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HISTORY OF THE GREAT WAR

BASED ON OFFICIAL DOCUMENTS

MEDICAL SERVICES, SURGERY OF THE WAR

VOL. II

EDITED BY

Major-General Sir W. G. MACPHERSON, K.C.M.G., C.B., LL.D.,

Major-General Sir A. A. BOWLBY, K.C.B., K.C.M.G., K.C.V.O.,

Major-General Sir CUTHBERT WALLACE, K.C.M.G., C.B.,

and

Colonel Sir CRISP ENGLISH, K.C.M.G.

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CONTRIBUTORS TO SUBJECTS IN VOLUME II

- AITKEN, D. McCrae, F.R.C.S., Captain R.A.M.C. (T.), Special Military Surgical Hospital, Shepherd's Bush. *Organization for Orthopædic Treatment of War Injuries: Military Orthopædic Centres.*
- EASON, H. L., C.B., C.M.G., M.D., M.S., Lt.-Col. R.A.M.C. (T.), Consulting Ophthalmic Surgeon, Forces in Mediterranean and Egypt, 1915-19. *Ophthalmic Work in Egypt.*
- ELMSLIE, R. C., O.B.E., M.S., F.R.C.S. Brevet-Major R.A.M.C. (T.F.) Special Military Surgical Hospital, Shepherd's Bush. *Amputations and Artificial Limbs.*
- FRANKAU, C. H. S., C.B.E., D.S.O., F.R.C.S., Colonel A.M.S. (T.), Consulting Surgeon, 5th Army, B.E.F., France. *Gunshot Wounds of Joints: Fractures of the Upper Extremity.*
- GILLIES, H. D., C.B.E., F.R.C.S., Major R.A.M.C. (T.), Officer i/c British Section, Queen's Hospital for Facial Injuries, Sidcup. *Injuries to the Face and Jaw.*
- GOULDEN, C. B., O.B.E., M.D., M.Ch., F.R.C.S., Captain R.A.M.C. (T.), Ophthalmic Specialist i/c Ophthalmic Centre, Rouen. *Injuries and Affections of the Eye: Wounds and Intraocular Foreign Bodies.*
- GROVES, E. W. Hey, M.S., M.D., F.R.C.S., Major R.A.M.C. (T.), Specialist in Surgery, Special Military Surgical Hospital, Bristol. *Orthopædic Treatment of Muscles, Joints and Bones: Ununited Fractures.*
- HARMER, W. Douglas, M.C. Cantab., F.R.C.S., Captain R.A.M.C. (T.), No. 1 City of London General Hospital. *Wounds of the Neck.*
- JONES, Sir R., K.B.E., C.B., F.R.C.S., LL.D., D.Sc. (Wales), Major-General A.M.S. (T.), Inspector of Military Orthopædics. *Orthopædic Treatment of Muscles, Joints and Bones: Stiff, Ankylosed and Flail Joints.*
- LEVICK, G. Murray, M.R.C.S., L.R.C.P., Surg.-Comdr. R.N. (ret.), Special Military Surgical Hospital, Shepherd's Bush. *Organization for Orthopædic Treatment of War Injuries: Remedial Exercises.*
- LISTER, Sir W. T., K.C.M.G., F.R.C.S., Colonel A.M.S. (T.), Consulting Ophthalmic Surgeon, B.E.F., France. *Injuries and Affections of the Eye.*
- MAKINS, Sir G. H., G.C.M.G., C.B., M.D., F.R.C.S., Major-General A.M.S. (T.), Consulting Surgeon, B.E.F., France. *Injuries to the Blood Vessels.*
- McMURRAY, T. P., M.B., M.Ch., Captain R.A.M.C. (T.), 1st Western General Hospital. *Orthopædic Treatment of Muscles, Joints and Bones: Tendon Transplantation.*

CONTRIBUTORS TO SUBJECTS IN VOLUME II

- | | |
|---|--|
| <p>MENDLESON, B., L.D.S., R.C.S.Eng., Captain (T.), Dental Surgeon, Queen's Hospital for Facial Injuries, Sidcup, and Dental Surgeon, No. 42 Casualty Clearing Station.</p> | <p><i>Injuries to the Face and Jaw.</i></p> |
| <p>MENNELL, J. B., M.A., M.D., B.C. Cantab., Officer i/c Massage Dept., Special Military Surgical Hospital, Shepherd's Bush.</p> | <p><i>Organization for Orthopædic Treatment of War Injuries: Massage during the War.</i></p> |
| <p>SCOTT, Sydney R., M.S., F.R.C.S., Major R.A.M.C. (T.), Adviser in Aural Surgery, B.E.F., France.</p> | <p><i>Injuries to the Ear.</i></p> |
| <p>SMITH, S. Maynard, C.B., F.R.C.S., Colonel A.M.S. (T.), Consulting Surgeon, 5th and 2nd Armies, B.E.F., France.</p> | <p><i>Fractures of the Lower Extremity.</i></p> |
| <p>THORBURN, Sir W., K.B.E., C.B., C.M.G., F.R.C.S., Colonel A.M.S. (T.F.), Consulting Surgeon British Armies, Malta, Gallipoli, Salonika and France.</p> | <p><i>Injuries to the Spine and Spinal Cord.
Injuries to the Peripheral Nerves.</i></p> |
| <p>TROTTER, W., M.S. Lond, F.R.C.S. Eng., Captain R.A.M.C. (T.), 3rd London General Hospital.</p> | <p><i>Gunshot Wounds of the Head.</i></p> |
| <p>USHER, C. H., M.B., F.R.C.S. Ed., Major R.A.M.C. (T.), Ophthalmic Specialist, Salonika Expeditionary Force.</p> | <p><i>Ophthalmic Work in Macedonia.</i></p> |
| <p>WAGSTAFFE, W. W., O.B.E., F.R.C.S., Captain R.A.M.C. (S.R.), Surgical Specialist, No. 7 General Hospital, France.</p> | <p><i>Gunshot Wounds of the Head.</i></p> |
| <p>WEBB-JOHNSON, A. E., C.B.E., D.S.O., M.B., F.R.C.S., Colonel A.M.S. (T.), Consulting Surgeon, B.E.F., France.</p> | <p><i>Fractures of the Lower Extremity.</i></p> |

Note. (T.) means temporary commission. (T.F.) means Territorial Force commission.
(S.R.) means Special Reserve.

PREFACE

THE subjects in this volume concern mainly injuries of various special parts of the body as distinct from the more general subjects of the surgery of the war dealt with in the first volume. But the extensive development of military orthopædics in the special military surgical hospitals in the United Kingdom gave rise to a vast amount of restorative work amongst officers and men who had been injured in the war, and consequently considerable attention has been given in the second volume to an account of this feature of military surgery. It is probably the first occasion in which work of this kind has been undertaken by the army medical authorities in connection with British campaigns.

Plastic operations for treatment of injuries to the face also formed a special feature in the surgery of the war, such as has not been recorded in previous wars.

In the chapter on Injuries and Affections of the Eye, the subject of trachoma occurring in the Chinese and Egyptian Labour Corps in France has been omitted, as the details of the important measures taken to prevent the spread of this disease are included in the volumes of the Hygiene of the War. Similarly, in the chapter on Injuries to the Ear, problems connected with ear troubles in aviation have been transferred to the chapters on the medical aspects of aviation in the second volume of the Diseases of the War.

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W. G. M.

November, 1921.



CHAPTER I.

GUNSHOT WOUNDS OF THE HEAD.

IT will be well to consider briefly what was the state of knowledge of the treatment of gunshot wounds of the head at the beginning of the war. Perhaps the best account on the subject, current at that time, is given in Sir George Makins' book, "Surgical Experiences in South Africa," which really formed the text book of military surgery. As regards the classification of wounds of the head, he divides the wounds into the following types:—

- (1) Scalp.
- (2) Fracture of cranial bones. No gross lesion of brain.
- (3) Fracture of cranial bones with concurrent brain injury.
 - (a) Through and through wounds of head.
 - (b) Vertical and coronal in frontal region.
 - (c) Oblique wounds.
 - (d) Fracture of base.

This is an incomplete classification, as is obvious with the present experience of a far larger number of wounds.

As regards the symptoms, his description applies of course mainly to rifle bullet wounds, and his outlook as regards sepsis, partly for this reason and partly for the reason of the greater cleanliness of the soil, is far more hopeful than has been the experience in the war of 1914–18, especially in the fighting in France, where shell wounds preponderated and where men frequently had their wounds infected by the soil of agricultural land.

His advice on treatment, however, is substantially that which has been adopted as the final outcome of the experience of the war, namely, operation as early as possible, excision of the wound in cases with fracture of the skull, enlarging of the aperture, removal of bony fragments and suture without drainage wherever possible. Owing to the very great difficulty of transport and the comparatively small number of cases, no special arrangements were made in the South African War for the treatment of head injuries.

Subsequent experience in the Russo-Japanese War did not cause any fresh development in the treatment of gunshot wounds of the head.

Classification.

It was early realized that in practically all cases of gunshot wound of the head, whether they did or did not involve a fracture of the skull, an injury to the brain was present, so that the classification as adopted by Makins was superseded. The rough classification used as a general rule came to be:—

- (1) Scalp wounds.
- (2) Compound fracture of skull ; no penetration of dura.
- (3) Compound fracture of skull ; dura penetrated.
- (4) Fractures of the base of the skull and concussion, unaccompanied by gunshot wound.

It was found that this was a good working classification, but from a detailed study of results compound fracture of the skull with penetration of the dura was found to include injuries of a greatly varying degree of severity. The classification proposed by Harvey Cushing is preferable as regards scientific accuracy. This classification is illustrated by him in Fig. 1. He has added to his figures the results that he obtained in a small series of cases, which show the variation in mortality of the various groups.

Fig. 1.

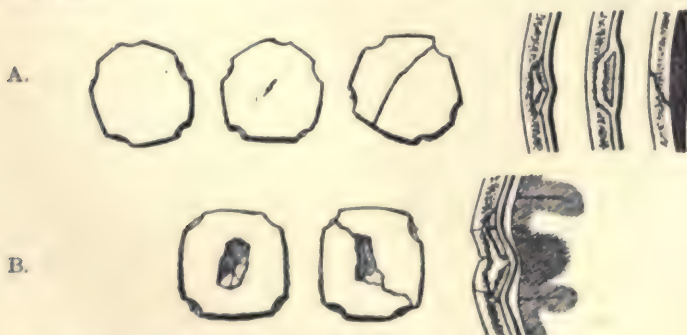
HEAD INJURIES GROUPED ACCORDING TO THEIR SEVERITY.
With mortality figures for each group under the condition recorded.

Group I.—*Wounds of the scalp, with intact cranium and dura.*

Occasional underlying cerebral contusion.

22 cases: 1 death (4·5%).

Group II.—*Wounds producing local fractures of various types, with the dura intact.*



Type A.—Without depression of external table.

Type B.—With depression of external table.

Local contusions of brain or extradural extravasation fairly common.

54 cases: 5 deaths (9·2%).

Fig. 1—continued.

Group III.—*Local depressed fractures of various types, with the dura punctured.*



Local contusions inevitable, usually with positive neurological signs; cerebral extrusion uncommon.

18 cases: 2 deaths (11·8%).

Group IV.—*Wounds, usually of gutter type, with detached bone fragments driven into brain.*



Local contusion severe, and extrusion of brain almost inevitable. Fungus cerebri, encephalitis, etc., common sequels.

25 cases: 6 deaths (24%).

Group V.—*Wounds of penetrating type, with lodgement both of projectile and bone fragments.*



Brain often extruding; contusion along track. Symptoms depend on size and course of missile. Common sequels: early compression, late abscess.

41 cases: 15 deaths (36·6%).

Fig. 1—*continued.*

Group VI.—Wounds with ventricles penetrated or traversed (A) by bone fragments, (B) by projectile.

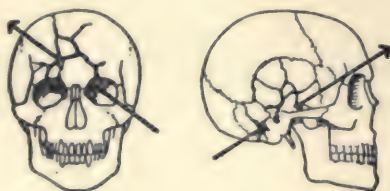


Cerebral lesion as in Groups IV and V, with cerebro-spinal fluid escape. Haemorrhage into, or subsequent infection of ventricle common.

Type A.—14 cases: 6 deaths (42·8%).

Type B.—16 cases: 16 deaths (100%).

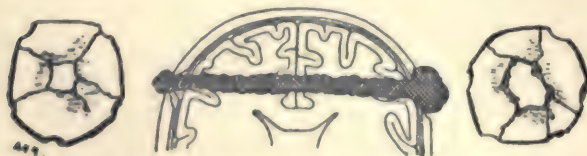
Group VII.—Wounds of cranio-cerebral type involving (A) orbital-nasal, (B) ²auro-petrosal region.



Brain commonly exposed and extruding; radiating fractures; nasal or petrosal cavities opened; meningitis common.

15 ²cases: 11 deaths (73·3%).

Group VIII.—Wounds with cranio-cerebral perforation.



Extensive cranial and cerebral damage common. Death usually due to intracranial haemorrhage and compression.

5 cases: 4 deaths (80%).

Fig. 1—*continued*.

Group IX.—*Cranio-cerebral injuries with massive fracture of skull.*



Widespread cerebral contusion. Compression phenomena common.
10 cases : 5 deaths (50%).

Scalp wounds (Group 1) form an important group, and are, as a general rule, far more severe than is at first suspected. They may be accompanied by a more or less severe cerebral injury and consequent paralysis or anæsthesia, and in a large number of cases wounds which are at first considered to be only scalp wounds may show an underlying injury to the cranium. Roberts, in 1915, emphasized the importance of this class of case. There is an important type of case in which the injury has been such as to produce no detectable fracture of the outer table but an extensive fracture of the inner table (Fig. 2).

This condition can only be diagnosed by means of X-rays, and serves to emphasize the importance of submitting all scalp wounds, wherever possible, to an X-ray examination. Adie and Wagstaffe report one death in 58 cases of scalp wounds, traced after leaving hospital, death occurring six months after wound from what appeared to be a cerebral abscess. This was probably a case of the type in which the fracture of the outer table had been overlooked.

Jefferson publishes a study of this subject, in which he points out the great proportion of cases in which cerebral injury is present, and emphasizes the severity of the injury.

In connection with the very frequent discrepancies that are met with between the ostensible and the actual amount of damage inflicted by gunshot wounds, it may be well to refer here very shortly to certain matters of general principle which have a direct practical bearing.

The damage inflicted by a blow on the head is proportional to the momentum or amount of force possessed at the moment of impact by the body which inflicts it. Now momentum is

the product of mass and velocity, and either of these elements may be the preponderating factor in a given case. In the head injuries of civil practice the mass of the moving object which causes the lesion is usually of far more obvious importance

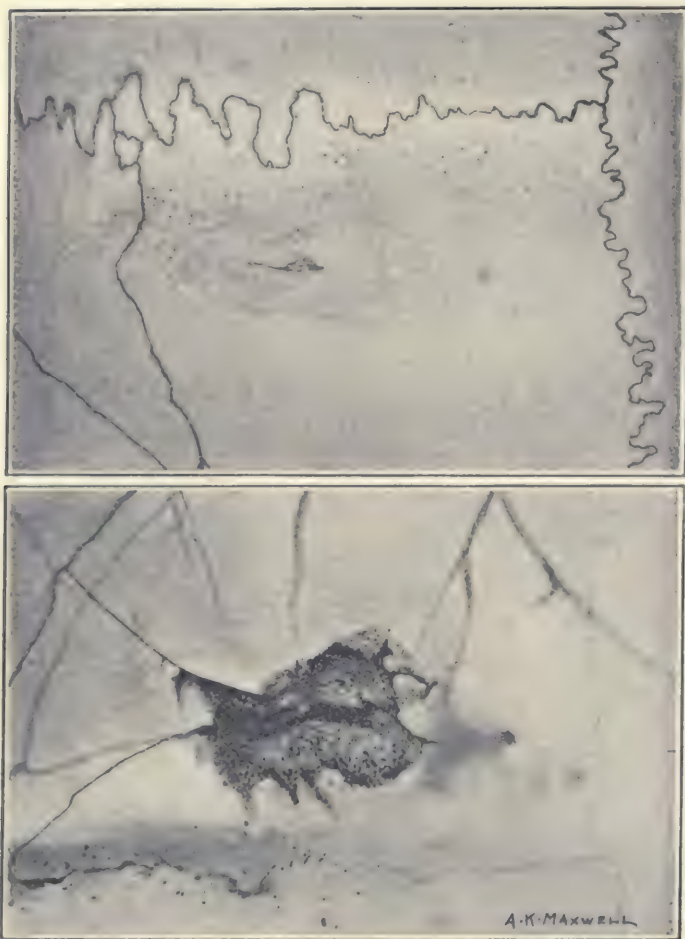


Fig. 2.—Illustrating fracture of internal table with a minimal degree of injury to outer table.

than is its velocity. One of the commonest causes of head injury in civil life, for example, is an accident in which the subject is thrown down and strikes his head on the ground. Here the momentum which causes the injury is derived mainly

from the mass of the patient's body, the velocity of impact being inconsiderable. There is thus a natural and misleading tendency to underestimate the damaging power of blows by moving objects of inconsiderable mass but high velocity, though the momentum they possess through the latter factor may be very great.

Another relatively unfamiliar effect of blows delivered at very high velocities is the way in which their force may be transmitted by soft tissues without the latter undergoing any very obvious destructive change. This is an effect of inertia and is in direct relation to the velocity of the blow. A glancing blow on the head by a slowly moving object will tear the scalp and leave the skull intact and unbent. A similar blow by a rifle bullet will allow no time for the soft tissues to be displaced and thus to spare the bone, but will cause scalp and skull to yield as one structure. Thus in such a case a mere graze of the scalp may be accompanied by a fracture of the bone and serious damage to the brain.

The skull is a highly elastic structure and is capable of being considerably indented and of recovering its shape without cracking. A localized blow on the head may cause grave contusion of the underlying brain without leaving any trace of fracture of the skull. While, therefore, a fracture shows that the skull has been indented beyond the limit of its elasticity, the absence of a fracture is not valid evidence that the skull has not been indented enough seriously to damage the brain.

It is important that the significance of loss of consciousness at the moment of a head injury should be precisely understood, otherwise the frequency with which consciousness is altogether unimpaired in spite of grave brain injury may prove to be misleading. Loss of consciousness following immediately upon a head injury implies that there has been a momentary anæmia of the whole cerebrum. This can be due only to a sudden and great increase in the general intracranial tension; such a rise of pressure is due either to a general deformation of the skull and consequent diminution of its capacity—as for example when a man is thrown on to his head—or to the passage through the skull of a high velocity projectile. Localized injuries of skull and brain, unless of extreme severity, do not produce a general rise of intracranial tension, and are therefore not usually accompanied by immediate loss of consciousness. While, therefore, early loss of consciousness is at least a usual feature of head injuries in civil practice,

there are very many cases of serious gunshot wounds in which it does not occur. The chief clinical inferences to be drawn from the foregoing considerations are that any contact of a high velocity projectile with the head must be regarded seriously, that the absence of serious damage to the scalp or skull is not exclusive of serious damage to the brain, and that the brain may have suffered serious local injury although consciousness was not lost at the time the wound was inflicted.

Cases of compound fracture of the skull with no penetration of the dura mater (Group II) may be of any degree of severity according to the degree of concussion or cerebral injury, and it may be impossible to tell whether the dura is or is not lacerated until the bone has been removed and the dura exposed by operation.

Cases of compound fracture of the skull with penetration of the dura (Groups III to VIII) may be of any degree of severity of injury to the brain, as is well seen in the figures given by Harvey Cushing. Not only do the symptoms vary according to the grade of severity of the anatomical lesion, but there is a vast variation in the severity of the initial symptoms in each class. Many cases have been observed in which men with severe penetrating wounds of the head (Group V for instance) have been admitted to a casualty clearing station as walking cases, whereas others with the same type of injury will be moribund on admission. Cerebral anæmia as a result of the injury, the degree of cerebral laceration and the presence or absence of intracranial hæmorrhage are the determining factors in the severity of the symptoms. As a general rule, too, the symptoms are more severe when the injury is near the base of the brain, though many cases have been observed with minimal symptoms although with a metallic fragment present and deeply situated in the brain tissue.

In many cases such as those above cited where the symptoms are comparatively slight at first and the patient arrives at the casualty clearing station as a walking case, the symptoms become progressively more severe. Here the question of sepsis is the governing factor, as indeed it is in the later stages of all gunshot wounds. The degree of infection throughout the war has been uniformly high owing to the large proportion of shell wounds. If the wound is not freely operated on and cleaned throughout its track as far as possible, the liability to sepsis is very great, and this factor is another powerful argument in favour of the full exploration of every gunshot wound of the

head, no matter what its degree of apparent seriousness. If an X-ray examination is feasible it should be done in every case. If, however, owing to any circumstances an X-ray examination cannot be done, the degree of severity of the wound must be carefully established by operation.

Cases of fracture of the base of the skull and concussion (with which is included Group IX of Harvey Cushing) as a rule most closely approximate to the concussion and fractured base seen in ordinary civil practice. They are caused in a variety of ways, either by the concussion of shell explosion or by a fall. They are not typically associated with any wound of the scalp. A peculiar type exists in which there occurs what may be called an "egg shell fracture" of the whole skull with no wound, and frequently very slight bruising of the scalp.

The essential lesion is a general deformation of the skull of momentary duration. It is necessarily accompanied by "concussion" of the brain in the technical sense of that term. There is usually a bursting fracture of the skull of which the so-called fracture of the base is part. Varying degrees of contusion and laceration of the brain are common, and the tearing of meningeal or cerebral blood vessels may cause progressive hæmorrhage.

General Treatment.

The general treatment of a gunshot wound of the head presents a problem essentially similar to that of a wound of any other part of the body; they are equally liable to the fatal complication of sepsis. Makins in 1902 laid down in his directions for the treatment of gunshot wounds of the head that operation should be as early and as thorough as possible with the object of cleansing the wound to the utmost degree. It was, however, found during the course of the war that cases of gunshot wounds of the head of all classes, except scalp wounds without concussion, stood the shock of transport very badly after operation. It was therefore recommended that they should not undergo operation until they reached a hospital where they could be kept for a period of from three to six weeks after the operation. With this end in view, such cases were admitted to and retained in hospitals in France as near the front line as possible. These hospitals were specially staffed with a surgeon and neurologist experienced in surgery of the head, and special facilities were given for the transport of patients thither from the casualty clearing stations.

This arrangement proved very satisfactory and wherever feasible was undoubtedly the best course. In times of heavy fighting such a subdivision of cases was certainly not practicable, and then each case was dealt with on its merits at the various casualty clearing stations.

The chief problem to be faced is always the surgical one—how to cleanse the wound so as to avoid the later onset of sepsis which is the cause of death in practically all cases after the first few days. This question has been the subject of great controversy. Some surgeons laid stress on the necessity of cleaning the wound and had a tendency to minimize the risk to the patient involved in transport after operation. Others minimized the risk of delaying operation, and concentrated on the necessity of operating under the best possible conditions with a staff accustomed to deal with such cases and in a hospital where the patients could be kept after operation.

There would appear to be truth on both sides, and it should be noted that the second opinion was formed largely as a consequence of the bad results obtained in head surgery in the early days of the war.

The final conclusions reached in the British army in France cannot be too strongly emphasized. They were to the effect that it was necessary to have a surgeon and a neurologist skilled in surgery of the head, to keep patients for at least three weeks before transferring them to another hospital, and to maintain an adequate nursing staff. Operations were to be performed as soon as these conditions were fulfilled.

The most favourable time at which to operate is as soon as the patient has overcome the primary wound shock and the shock of transport from the line. Not more than twelve hours should be allowed to elapse between the time of wounding and the time of operation. The special hospitals should be so placed that patients can be transported thither from any part of the line, and yet be in a condition to undergo operation within that time. Of course in many cases it will not be possible to realize these conditions, and frequently transport from the front line can only be undertaken at certain definite periods. It should be realized that transport of head cases to hospital is as urgent a matter as, for instance, is that of cases of penetrating wounds of the abdomen, and every possible facility should be given for early transport to the special hospitals where they can receive the best treatment.

The actual technique of the operation has passed through a variety of stages corresponding with the treatment of gunshot

wounds generally. There was the first stage in which the wound was treated by incision and drainage; the second stage of treatment by various antiseptics, such as Carrel-Dakin solution and B.I.P., with more or less cleansing of the wound by removal of debris; and the third stage, which was reached comparatively early in the case of gunshot wounds of the head, of complete excision of the wound edges and the cleansing of the track as far as possible. It will be seen how closely this final stage approximates to the treatment recommended by Makins in 1902.

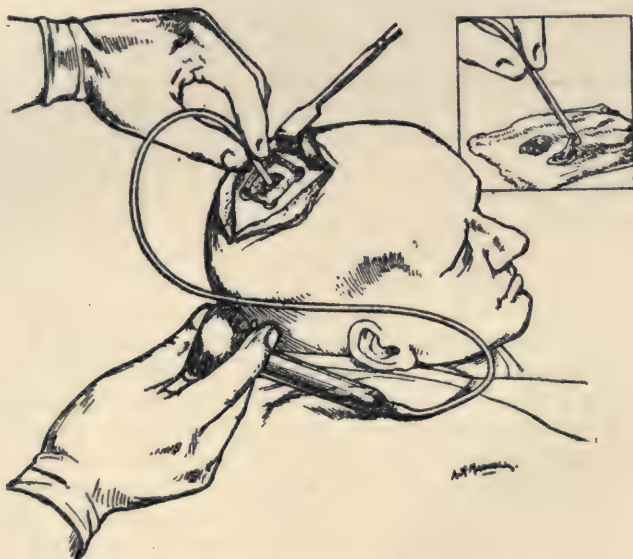


Fig. 3.—Carrel syringe with catheter attached, as used by H. Cushing.

The actual stages of an operation for a penetrating wound of the head may be described as follows:—The patient's head is completely shaved and cleaned. The head being placed in the most convenient position for the operation, the wound is carefully excised, together with all underlying damaged tissue in the scalp as far as possible. The bone is then widely exposed either by prolonging and extending the incision, or by means of a horse-shoe shaped flap. The hole in the bone is next enlarged by means of a rongeur so as to expose a ring of healthy dura about half an inch wide around the penetration of the dura. The track of the wound in the brain is then carefully

explored and any fragments of bone or metal that can be felt are removed. The X-ray examination that should be made before the operation will indicate the size, position and number of these fragments, and every effort should be made to remove all fragments if this can be done without increasing the damage to the brain. Cushing has recommended a very ingenious method of removing these bony fragments and cerebral debris. (Fig. 3.)

He uses an ordinary Carrel syringe to which is attached a rubber catheter. This rubber catheter is inserted into the brain and the syringe which is filled with normal saline solution is used to wash out small debris. On releasing the rubber bulb, larger fragments of debris and small pieces of bone are caught in the eye of the catheter and are removed when the catheter is withdrawn. This method will be found invaluable in the cleansing of the track of the wound in the brain, but for the removal of large fragments forceps should be inserted, guided by the finger. Digital exploration is generally indicated as the quickest and most satisfactory method of exploration, but should be done only with the greatest gentleness and care.

Cushing recommends the complete excision of the bone around the perforation *en bloc* as a means towards the more complete cleansing of the wound, but the operation is tedious and the end aimed at is not attained. It is, however, indicated when a wide simultaneous view of the dura is necessary as in injuries to the superior longitudinal sinus.

Considerable difference of opinion has existed as to the best form of anæsthesia. A large number of surgeons, including Gray, Cushing, de Martel and most of the French surgeons worked with local anæsthesia. This method has the advantage of assisting hæmostasis of the scalp and avoiding the disturbance of the cerebral circulation necessarily associated with a general anæsthetic and also the disturbance of post-anæsthetic vomiting. The majority of British surgeons, however, adhered to the use of a general anæsthetic for the following reasons:—

- (1) The majority of patients, while not unconscious, are at least in possession of some control of themselves, and are liable to make sudden movements which are fatal to the success of the operation. They also resent the covering of the face and similar inconveniences to which the patient must necessarily be put in these cases.

- (2) The factor of time is important where a large number of cases have to be dealt with. It is common experience that to obtain a perfect state of anæsthesia by means of a local anæsthetic takes from ten minutes to a quarter of an hour longer than by means of a general anæsthetic.
- (3) Freedom for the surgeon in his operating field is essential and is difficult and frequently tedious to ensure to an adequate extent when anæsthetization is local.

Post-anæsthetic vomiting and restlessness can be combated by means of large and repeated doses of morphia. A preliminary injection of morphia, atropine and hyoscine before the operation, if it is certain that the patient has not recently had large doses of morphia, will materially assist the anæsthesia.

Perhaps the best method of all is a light general anæsthesia with a local injection of novocain and adrenalin along the line of the incision, thus diminishing the amount of general anæsthetic necessary and producing the desired hæmostatic effect.

As a general rule, every case of injury to the head should undergo an X-ray examination on admission to hospital. An antero-posterior and a lateral view should be taken in all cases, and the plates or prints should accompany the patient on leaving hospital so as to obviate the necessity for fresh X-ray examination on admission to another hospital.

It will be realized that, if the patient is to be transferred to a special hospital and got ready for operation within a space of twelve hours from the time he is wounded, there is need for the greatest expedition in passing him through the various stages, and that, in times of stress when there is a great number of seriously wounded patients, it is impracticable to comply with all these conditions. Each case must then be judged on its merits, taking the general line that the most important point is to get the patient operated on within the shortest possible time under the best possible conditions. In certain cases, notably those of penetration of the dura with fragments of metal or bone lying or driven into the brain, the operation cannot be regarded as satisfactory unless an X-ray examination has been made previous to operation, so as to indicate the size and position of all the fragments. Great efforts should therefore be made in this type of case to have a thorough X-ray examination performed, and if this is impossible, the surgeon must realize that he is working under a very severe

disadvantage, for he will have to establish by examination during the operation what is the exact degree of severity of the wound, a point which would, in a large proportion of cases, have been at once elucidated by the X-rays. In no cases, however, should operation be long postponed because of the impossibility of an X-ray examination.

One difficulty frequently arises in connection with the X-ray examination of patients, namely, the impossibility of doing the examination owing to the restlessness of the patient. In these cases X-ray examination must be dispensed with, though many cases that are apparently impossible to deal with may be successfully examined by a clever and patient X-ray operator. In no case is it justifiable to anæsthetize the patient for the X-ray examination, but in many cases an injection of morphia will be of the greatest assistance.

To sum up, every case of gunshot wound of the head should be examined by X-rays on admission to hospital, but operation should not be delayed owing to the impossibility of the examination, whether owing to the pressure of work or to the restlessness of the patient. In selecting cases for X-ray examination, when it is impossible to examine all cases, priority must be given to those with penetration of the dura.

Treatment of Various Types of Head Injury.

As has already been pointed out, scalp wounds should in all cases be excised and carefully explored. If there is no injury to the bone, the wound is sutured either completely or with a small drain at one end so as to prevent the collection of a hæmatoma. Undercutting of the edges or the cutting of a small flap may be necessary to secure proper apposition of the edges.

An ingenious method is suggested by Sir Cuthbert Wallace for relieving tension. It is best illustrated by Fig. 4.

In cases of compound fracture of the skull with no penetration of the dura, the problem before the surgeon is the efficient cleansing of the wound. This can be done only by the removal of the depressed fragments, which can be effected either by piecemeal removal or by removal *en bloc* as recommended by Cushing.

In the case of long fissured fractures with no depression or comminution of the bone such removal is not practicable. All that can be done then is to cleanse the wound as carefully as possible.

A certain class of case has given rise to much discussion. The question has been asked whether in cases which are admitted unconscious or restless and irritable with compound depressed fracture of the skull, in which on operation no perforation of the dura is found, the dura should be incised. In a large proportion of cases, if it is incised, a layer of blood only—not more than a quarter of an inch thick—will be found on the surface of the brain, which may or may not be lacerated at this point. The risks of sepsis are enormously

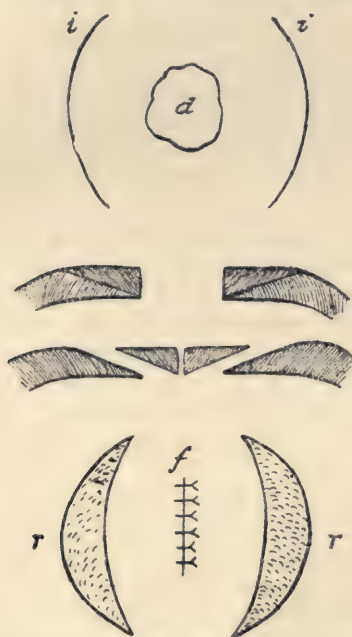


Fig. 4.—Method recommended by Sir Cuthbert Wallace for relieving tension in scalp:
i = lateral incision; *d* = defect; *f* = flaps
 sutured; *r* = raw surface.

increased. The final opinion of the majority of surgeons was that only in the very exceptional cases of definitely increasing intracranial pressure was this serious step in the operation justifiable. The signs of increasing intracranial pressure are gradually deepening unconsciousness, the spread of paralysis, if present, a pulse rate which is either slow and feeble or more frequently rapid and running, and a rising temperature.

The diagnostic problem in such cases is to distinguish a definite progressive hæmorrhage, which would be fatal if

unrelieved, from a reactionary œdema accompanying contusion and laceration in which operation may be withheld without undue risk. Progressive paralytic phenomena, such as loss of pupil reflex, monoplegia and hemiplegia, are certain evidences of hæmorrhage. Unconsciousness alone, even although profound, if unaccompanied by progressive paralytic signs, is quite compatible with a mere œdema. Bulbar phenomena (slow deep respiration, slow pulse, rising blood pressure), even though evidence of increased excitability rather than paralysis, are in themselves very serious, and usually indicate a condition from which recovery is not possible without operative relief of intracranial tension. In doubtful cases, the question of a decompressive operation away from the wound such as withdrawing fluid from the spinal canal should be considered as possibly affording some relief with less risk of sepsis than would accompany incision of the dura in the wound.

The treatment of compound fractures of the skull with penetration of the dura has already been fully considered under the heading of general treatment.

The treatment of cases of fractured base of the skull and concussion follows the lines laid down for the treatment of such injuries when seen in civil practice. Operation may be indicated by the following conditions :—

- (1) Progressive hæmorrhage producing definite paralytic symptoms.
- (2) Prolonged "cerebral irritation" due to contusion, laceration, and the accompanying reactionary œdema. Although recovery, even after several weeks of delirium or unconsciousness is possible, surgeons who recommended operation in such cases state that the condition can usually be promptly relieved by a decompressive operation. It is probable that when such an operation is done early there is a diminished liability to sequelæ, such as chronic headache, epilepsy and mental degeneration.
- (3) Sepsis spreading from the fracture in the base of the skull.

The injuries, as a rule, are far more severe than those seen in civil practice, and prolonged unconsciousness, in many cases for more than a fortnight, marked irritability and restlessness are frequent. The administration of morphia and occasionally the operation of lumbar puncture assist in the treatment of this condition

Special Types of Injury.

Injury to the longitudinal sinus was of comparatively frequent occurrence, and is fully described by Sargent and Holmes. The condition is characterized by a bilateral paralysis affecting the legs and frequently the arms. The parts affected most are the ankles, and then the hips, shoulders, elbows and wrists in order of frequency. Rigidity is a prominent feature with very well marked adductor spasm. Sensory loss of the cortical type is present.

The injury causing the lesion is a gutter or tangential wound in the middle line of the head at the level of the fissure of Rolando or posterior to it. The outer table of the skull may or may not be fractured, but the sinus or its lacunæ are compressed or lacerated by depressed fragments of the inner table. Sargent and Holmes state that the condition is caused by thrombosis of the cerebral veins and the longitudinal sinus. Cushing doubts this explanation, and attributes the whole of the symptoms to contusion of the vertex involving the mesial surfaces of both hemispheres, and resulting in bilateral spastic paralysis of the lower extremities, with perhaps an accompanying palsy of one or both arms. Saviozzi agrees with this explanation.

Sargent and Holmes, owing to the unsuccessful results which they had seen, recommended that in these cases the depressed fragments of bone should not be removed. This was, however, in the early days of the war, when the principles of the cleansing of wounds were not fully understood. Harvey Cushing recommended operation in all cases. There is no doubt, however, that the operative treatment of these cases requires a very special degree of technical skill, and unless the surgeon is prepared to proceed on Cushing's lines and excise the fracture *en bloc*, thus giving himself a thorough view of the tear in the sinus, he will be well advised not to touch the bone.

Cushing gives records of operation in these cases. His technique may be briefly described. After excision of the scalp wound and exposure of the skull by extension of the incision, four or more holes are made in the bone around the site of fracture. These holes are made by means of any modification of the ordinary brace and bit, such as Doyen's drill (Fig. 5), a method which in capable hands is perfectly safe, and is far less laborious than the use of a trephine. It should be used in all cases where a hole is required

to be made in the skull. The holes are then joined by means of cutting forceps. Cushing used a form of forceps known as Montanovesi's. The section of the bone across the mid line should be the last part of the operation to be performed because of the risk of further hæmorrhage. When the block of bone including the site of fracture is perfectly freed, it should be raised from the dura, and at this point of the operation very severe hæmorrhage may occur. This should be controlled at once by means of a gauze plug held in position by the fingers. The point of origin of the hæmorrhage is then explored, great care being taken to avoid any large loss of blood. Hæmorrhage is controlled in the case of small lacerations by means of a small pledget of muscle or fascia cut from the under surface of the scalp, and held in position for a few minutes by the finger, according to the method originally suggested by Sir Victor Horsley. Failure of this method can only be due to



Fig. 5—Doyen's drill.

the insufficient size of the graft (in which case a larger piece should be applied), or to the large size of the aperture. If this latter is the case it may be necessary to apply one or more fine stitches to bring the edges of the rent together, finally sealing the repair by means of a graft. When the hæmorrhage is once controlled the wound is treated in the routine manner, brain pulp and bone and metallic fragments are removed, and the scalp edges approximated and sutured.

It is well to emphasize the difficulty of this operation, and also to state that it should not be performed except in cases where there is a reasonable chance of the wound healing without suppuration. Cases that are received later than twelve hours from the time of wounding should not be touched, as the risk of hæmorrhage is very great.

Cerebellar and Occipital Injuries present no special surgical points. Great neurological interest attaches to them, however, and Holmes has studied the symptoms of injury to the cerebellum and the localization of function in the cerebellum. He also discussed the question of the localization of function in the occipital lobe, and mapped out areas of the brain corresponding with areas of the field of vision.

Complications.

Adie and Wagstaffe studied the complications in a series of 656 cases of gunshot wound of the head, admitted to No. 7 General Hospital, St. Omer, from 1916 to 1918. A large proportion (70 per cent.) of the cases were sent direct to No. 7 General Hospital for operation and subsequent treatment, and they were kept there until convalescent. The average length of stay for cases with penetration of the dura was 41 days before evacuation to England. The following is an extract from their account of the complications noted:—

"Fits."

"In the cases which recovered fits occurred in 23 (5 per cent.). The time of onset was always within the first seven days after the patient had been moved from the casualty clearing station after operation, or after operation at the hospital here, and most occurred on the day after admission, in those cases already operated on at the casualty clearing station, or on the day after operation in those cases sent direct to us. The time of onset depended on this movement or operation and bore no definite relationship to the time that had elapsed since the man was wounded.

The fits varied from slight twitching of a part to generalized convulsions with loss of consciousness. In fifteen cases the fits, beginning on the side opposite to the wound, became general and consciousness was lost. Of the remainder, in six the fits were localized to one part or to one side, and the patient did not lose consciousness. One man with a non-penetrating occipital wound had visual fits, without loss of consciousness, and another suffering from a non-penetrating wound in the right temporal region had gustatory fits, during which he had, as he said, 'a nasty taste like antiseptics' in his mouth and a 'queer feeling' in his head.

The attacks varied greatly in number from a single fit in ten cases up to twenty or thirty; but in no case did a fit recur once the bout was over, although the cases were under observation for three weeks or more. A definite relationship exists between the nature of the wound and the occurrence of the fits. They were commonest in cases of scalp wounds, in which at the operation no injury to the skull was apparent, or in which an intact or very slightly damaged dura was found under a depression. Of the remainder in which the dura was penetrated, the majority occurred in cases which had been operated on at the front, and very few in cases which had been operated on at this hospital and kept quiet, although the great majority of penetrating head wounds observed were operated on here.

In fatal cases fits were not so common. Generalized convulsions were rare, and the commonest type of seizure was a twitching, most often of the face alone, sometimes more widespread, which continued off and on for hours, sometimes for days. This was, as a rule, evidence of cortical meningitis spreading up from the base along the Sylvian fissure over the motor area and was merely an incident in the last days of a patient already dying of basal meningitis.

Contrast these fits in fatal cases with those first described. In those cases which ultimately recover the fits occur during the first week after movement or operation; they begin in a part corresponding to the position of the wound; generalized convulsions are common; they are of considerable violence and of short duration; they are perhaps the only alarming clinical sign and their significance is slight. In the fatal cases the attacks may commence any time after admission; they begin in parts not necessarily related to the site of the wound; continuous twitchings are the commonest form, and the patient is already seriously ill. If meningitis has not yet been diagnosed, their significance is great when added to the other symptoms; if it has, they only make an already bad prognosis worse.

Briefly, then, fits occurred in five per cent. of the recoveries. They occurred during the first week after admission; they were never spread out over a period longer than three days; they never recurred, and they were most common in cases where no operation was done on the skull, or where the dura was intact or the brain only slightly damaged.

It will be noted that in these cases there was an exact correlation between the site of the wound and the nature and point of origin of the fits. An occipital wound caused visual fits, a temporal wound caused gustatory fits, and wounds over the motor areas caused convulsions.

This distinguishes these early cases sharply from those in which epilepsy develops late as the result of a head wound—traumatic epilepsy in which, it is said, no such correlation exists.

Are these men who have had fits early, and who perhaps have had an operation performed on the skull, more likely to develop traumatic epilepsy than any other cases of head wounds? Nothing that we have learnt from the replies that we have received from home of the after results of these cases leads us to believe that they are.

Does the occurrence then of fits alone justify an operation on an intact skull? We think the answer is, No.

Meningitis.

In those cases which survived the shock of the wound and operation, meningitis was the cause or partial cause of death in the majority of our fatal cases.

In every case except four the dura was penetrated; in two there was no fracture of the skull and the path of spread of the infection was not discovered; in two the infection spread through an apparently intact dura.

Symptoms may appear at any time after admission as our patients arrive at various times after being wounded.

In cases operated on at the base and kept there the patient often appears to do well until the seventh or tenth day after operation. We only begin to feel happy about cases, so far as meningitis is concerned, when fourteen days have elapsed, without any untoward signs. The earliest sign to be noted may be that, with or without any rise of temperature, the patient becomes 'much brighter.' He is talkative and amuses those around him with his quaint criticisms and remarks on his surroundings. Or more commonly he becomes querulous and is considered by inexperienced nurses to be merely 'naughty.' Within twenty-four hours, however, he begins to complain more insistently, the temperature rises, the neck becomes stiff, the ominous cry, 'Oh, my head,' is heard; he becomes very restless, especially at night, and the typical meningitis is developed. All the fatal cases died within the first six weeks, the great majority before the end of the third week.

On post-mortem examination, basal meningitis and a rupture into the lateral ventricle were found in sixteen cases, basal meningitis alone in four, cortical meningitis alone in two, a combination of cortical and basal meningitis in seven, and this combination with rupture into the ventricle in five; so that all the fatal cases had basal meningitis except two, and in all except thirteen the lateral ventricle had been opened.

All the cases are not fatal, however, as we have seen several men with all the signs of meningitis and with an infected cerebro-spinal fluid make a complete

recovery. To illustrate the fact that no case is hopeless we mention the case of a man, who developed a definite meningitis. He was delirious—temperature 104°; he had nystagmus and severe hiccough, and his case looked quite hopeless. He also had a large hernia. One day when being dressed he suddenly put up his hand and reduced his hernia. He made a good recovery. . . . He is the only case of meningitis that we have seen develop hiccough and recover.

In the treatment of many of these cases lumbar puncture was done and we think it should be done in all and repeated as long as a free flow of fluid is obtained. Unfortunately after two or three punctures only a few drops of fluid are obtained in most cases, showing that the foramen of Magendie is blocked and that it is useless to persist.

More elaborate methods of treatment, such as washing out the ventricles and spinal canal, have not been tried.

Cerebral Abscess.

Fourteen cases of cerebral abscess were observed—twelve with penetrating wounds, two with non-penetrating wounds. The cases fell into two definite clinical groups. First, those typical of cerebral abscess alone (nine cases), and second, those in which the symptoms of abscess were complicated by infection of the membranes.

The cases in the first group ran a similar course, and it is possible to give a general description which will apply to all with the exception of three cases which will be mentioned later.

In all these six cases the dura was penetrated and the brain severely damaged. The usual operation was done on admission. The wounds did not heal by first intention, but suppurated for a varying time and then either healed (three), or continued to discharge a small amount of pus (three).

The temperature, irregular for a few days at first, settled. The patient was quiet and seemed to be doing well. This quietness, pleasing at first, soon aroused suspicion. When spoken to, the patient answered sensibly, and made no complaint except, perhaps, of slight headache. But left to himself, he showed little interest in his surroundings, he never started a conversation himself, he wrote no letters, he never read the papers. He began to get thin and seemed to have lost his inclination for food. The temperature became sub-normal with an occasional rise to 100°—101° which settled again in one or two days. The chart also showed a gradual slowing of the pulse, week by week. This was not evident on merely glancing at the chart, but came out clearly on close analysis. Sooner or later, generally about the sixth week, an occasional pulse reading in the low fifties appeared. The patient then began to vomit and the stage of fully developed abscess was reached.

The patient is now very quiet—he lacks volition—he vomits occasionally but may complain little. He is pale and thin. A tense hernia has formed under the healed scalp wound, or a hernia, present from the first, has increased in size. Any neurological signs which were present at first have increased in severity, or new signs have appeared. Optic neuritis is present in most cases (four out of six). The pulse is slow and the temperature is mainly sub-normal.

The patient remains in this condition, perhaps, for several weeks, and then comes the end, which is as sudden as the onset was gradual.

He suddenly becomes worse, the temperature shoots up, the pulse-rate is greatly increased, and death takes place within forty-eight hours from rupture into the lateral ventricle. Or, soon after operation, the temperature rises and the patient dies from meningitis or a spreading encephalitis.

The average date of death was the seventieth day after being wounded. The earliest death was on the thirty-fifth day. One lived 122 days.

On post-mortem examination in all these cases well localized abscesses were found deep in the brain at a distance from the track of the wound, and often in silent areas. There was one abscess in two cases only, in three cases there were two, and in one there were five. Two abscesses contained fragments of in-driven bone, in the remainder no foreign body was found.

The lateral ventricle was opened in four cases, in one by rupture of the abscess itself, in three by the extension of a softening process from the track of the wound. In two the ventricle was intact.

One case showed well-marked old basal meningitis; in two the membranes were uninfected; in three there was recent cortical or basal meningitis.

An operation was done and an abscess found and drained in all but two of these cases without materially affecting the result.

This account is intended to give an idea of the course in the majority of the cases suffering from cerebral abscess alone. In two cases we were more fortunate. In one the abscess was drained and healed, but the patient died from other causes—he had a fractured femur; in another the patient made a complete recovery. This patient was admitted to this hospital on November 14th, 1917, with a scalp wound in the right parietal region, over the lower part of the motor area. His general condition, except for some bronchitis, was very good. He had no paralysis. He was operated on next day when the scalp wound was excised and the skull examined. No fracture was detected and the wound was sutured. The wound healed by first intention except at one point in its centre which discharged a small quantity of pus. The temperature was irregular for the first ten days but as he had bronchitis and did not complain of his head, little importance was attached to this. After the tenth day the temperature was normal, generally sub-normal, and all went well until the twenty-second day when he vomited several times. This was attributed by the nursing staff to his having eaten tinned rabbit. He was very quiet when left alone but bright when roused; when questioned he complained of headache. He was not taking his food well, was rather pale and looked a little thinner. His pulse was slowing down and a reading in the fifties had appeared for the first time that day. His temperature was nearly always below 98·4°, but had risen twice to 99° in the preceding ten days.

On further examination we thought that the left abdominal reflexes tired more easily than the right, and that the veins of the fundus were slightly engorged, and the inner edges of the disks slightly hazy. Next day he said he was much better, but he did not look it. His pulse was 50, his temperature 98°, and a slight weakness in the movements of the left side of the face was detected. Next day he vomited again, once only; his headache was worse his pulse fell below 50 at times, and a definite but very slight loss of power in the grasp of the left hand which had not been there before was found.

The diagnosis was now made, and looking back we felt that it should have been made sooner. But was there enough to go on? He only had a scalp wound we thought. It is common enough to see a slow pulse in convalescent head cases—many patients in bed run a sub-normal temperature, and it is just these cases of scalp wound which have the most persistent headaches.

It was the weakness in the face and arm that made the diagnosis certain.

We make this case the justification for a plea that all head cases should be examined neurologically on admission, and that a note should be made of what is found. A very simple examination will suffice, but it must be accurate. In the case just described, if we had not been absolutely certain that there was not the slightest trace of any weakness on the left side on admission—as well there might have been considering the situation of his wound—several valuable days might have been wasted before we could have been certain that his signs were due to some new process.

As soon as the diagnosis was made he was operated on; a small crack was found in the bone which had not been seen at the first operation, and did not show on the X-ray plate, bone was removed, and the abscess in the brain was drained. The patient made a perfect and uninterrupted recovery.

In the five cases of the second group the signs and symptoms of abscess and meningitis were so united that it is not possible to give a single description which would be typical of all.

The temperature was irregular throughout, and the pulse did not show the slowing seen in the first group. The patients were restless and noisy, a large hernia developed early, and the whole course of the illness was more rapid.

The average date of death was the forty-fifth day. A single abscess was found post-mortem in all these cases, not shut off, but surrounded by a wide area of softened brain. In three cases the abscess had formed in a hernia; in the other two it had formed in the track of the wound. Bone fragments were found in the abscess in three cases. The lateral ventricle was opened in four cases—in all five the ventricle contained thick greenish pus. Meningitis was present in all. In these cases the abscess was merely a part of a widespread infection of the brain and its membranes.

Of the fourteen cases it will be seen that twelve were fatal from brain sepsis and one from other causes, and that one recovered.

We hope that we have learnt something from the above cases which will enable us to operate earlier and improve on these bad results.

Cerebral Hernia.

The increased intracranial pressure, of which cerebral hernia is a sign, may be set up and maintained by infection, or it may arise with or without infection, and the hernia once formed may be kept up mechanically.

The hernia may be merely a sign of an abscess in the brain, or an abscess may form within the hernia itself, whatever its original cause.

In every fatal case of meningitis a hernia formed where this was physically possible. In those cases where no hernia was noted, either the dura was intact, or the entrance wound into the cranium was through some part which prevented an operation to enlarge the bony opening, or there was a free escape of cerebro-spinal fluid which kept down the intracranial pressure or finally the infection caused death within a few days before hernia had time to develop.

In cases of meningitis which recovered a hernia was always present, and the hernia receded as the infection was overcome. In many cases with signs of increased intracranial pressure which recovered, where infection was suspected but not proved, a hernia was present, and it receded as the cerebral symptoms abated.

But when all these cases were excluded, there remained a few cases in which a hernia, whatever its original cause, persisted for weeks after all signs of infection had disappeared. In these cases the cause of the persistence of the swelling is apparently a mechanical one, and seems to be due to insufficient bone removal at the original operation.

Hernias are seen most often in cases operated on at the front and moved to the base soon after operation, but a few occurred, in a much smaller proportion, in cases operated on at the base, and kept there for several weeks.

As a rule the hernia slowly receded with rest in bed alone, and of the few cases sent to England with an unhealed wound, only three had a hernia larger than a golf ball, and these were gradually becoming smaller.

For the treatment of cerebral hernia, rest in bed, with the patient sitting up for a few hours daily, and the application of a bandage exerting slight pressure were found to be sufficient in all cases. Operations to increase the size of the bony opening were never performed, as we were aware of the danger of secondary operations in head cases. Lumbar puncture as a routine treatment in cases of uncomplicated hernia was not thought to be necessary.

Apart from infection, insufficient decompression and early transport after operation are conducive to the formation of a hernia. In every case, if the infection has been overcome, the hernia gradually recedes under the simple treatment mentioned above."

Prognosis.

The immediate results of gunshot wounds of the head show a very great mortality. A large proportion of men with head injuries never reached a hospital at all.

The following tables give the results of a series of 740 cases which were under the care of Major Wagstaffe in France. They have been under observation for a period of from two to four years. It has not been possible to compare these figures with the results of other surgeons, for no other statistical report on complications has been found.

From Table I will be seen the low proportion of patients who returned to the army in all classes of head injury, and the still smaller number who found their way to the fighting line again.

TABLE I.

Results of total series—740 cases of G.S.W. head.

	G.S.W. head penetrating dura.	G.S.W. head, co. frac. skull, dura not penetrated.	Scalp Wounds.	Frac. Base and Concussion.
Totals	389	192	136	23
Gross mortality ..	55.7%	18.0%	4%	35%
Recovery without com- plications	9.7%	33.6%	86%	37%
Returned to army ..	3.1%	26.2%	60%	33%
Returned to fighting line	0.8%	9.0%	26%	17%

In Table II an analysis is made of all the cases of gunshot wound of the head with penetration of the dura which were treated. Of these 23 per cent. were observed to have a metallic fragment retained in the brain which was not removed at operation. It is of interest to note that the late results in cases with a retained metallic fragment do not seem to be materially worse than the generality of penetrating wounds of the dura.

The mortality is analysed according to the time that has elapsed between the date of wounding and death. It will be seen that the great majority die within ten days of reaching hospital. These include all the cases where death is due to intracranial hæmorrhage and cerebral laceration and also all the cases of acute septic infection. Death in the later stages, when not due to intercurrent disease, is always due to some form of intracranial sepsis.

The complications that may occur during recovery are analysed. Persistent paralyses and anæsthesia are found in 19 per cent., or 43 per cent. of recoveries. Early fits were

noted in 2·2 per cent., or 5 per cent. of recoveries, and traumatic epilepsy in approximately the same number; but it is to be noted that in only one case where traumatic epilepsy occurred had early fits been present. Mental complications are small in number, 1·1 per cent. or 2·5 per cent. of recoveries. In connection with this it is to be noted that apart from cases where the symptoms are of very early onset, there is a definite type of gradually increasing mental deterioration associated more especially with severe wounds of the frontal region with marked suppuration and destruction of cerebral tissue.

No complications are found in only a comparatively small number of cases. The commonest symptoms, apart from those already mentioned, are headache and dizziness, especially on stooping. This causes a great disability in a large proportion, and is a very definite problem in the treatment of the late results of gunshot wounds of the head.

Cerebral hernia was present in 6·2 per cent., excluding those cases that died in which cerebral hernia was present.

TABLE II.

G.S.W. Head with penetration of dura.

Results in 389 cases.

<i>Mortality.</i>							<i>Per cent.</i>
Died in hospital, 1 to 10 days after wound	..	..	..	..	..	..	38·0
Died in hospital, 10 days to 6 months	..	..	..	..	..	..	12·0
Died after more than 6 months	..	..	..	..	..	..	5·7
<i>Recovery.</i>							
Percentage recovered	..	..	..	..	..	..	44·3
Persistent organic complications, paralysis or anæsthesia	..	..	..	..	..	..	19·0
Early fits	..	..	..	..	..	..	2·2
Traumatic epilepsy	..	..	..	..	..	..	2·2
Mental complications	..	..	..	..	..	..	1·1
Cerebral hernia	..	..	..	..	..	..	6·2
No complications	..	..	..	..	..	..	9·7
Returned to army	..	..	..	..	..	..	3·1
Returned to fighting line	..	..	..	..	..	..	0·8

Table III is an analysis of the observed recoveries. Apart from the cases of penetration of the dura which have already been considered in connection with Table II, the following observations may be made:—

Persistent organic complications occur in a high proportion of cases, in both the groups of depressed fracture and fractured base. Certain cases also of scalp wounds show this persistent complication. The most frequent symptoms present are hemiplegia, hemiparesis and aphasia.

In connection with hemiplegia it is noted that if the patients have shown an improvement within the first few days they may continue to improve and in some cases entirely recover (3 out of 18). If, however, they show no improvement at first, they never improve. In aphasia, recovery is usually complete, (11 out of 16).

No correspondence is established between early fits and late traumatic epilepsy. In all classes of injury, headache and dizziness are severe and are persistent complications.

TABLE III.

Analysis of Recoveries. Cases of G.S.W. Head.

	G.S.W. head, dura penetrated.	G.S.W. head, co. frac. skull, dura <i>not</i> penetrated.	Scalp Wounds.	Fract. base and concussion.
Total number of recoveries..	224	170	135	17
Persistent organic complica- tions, paralysis, or anæsthesia.	43% of recoveries.	21% of recoveries.	3% of recoveries.	35% of recoveries.
Early fits	5% of recoveries.	4·8% of recoveries.	2·5% of recoveries.	12% of recoveries.
Traumatic epilepsy	5·2% of recoveries.	0	3% of recoveries.	0
Mental complications ..	2·5% of recoveries.	1·5% of recoveries.	0	0
No complications	22% of recoveries.	41% of recoveries.	90% of recoveries.	58% of recoveries.

In connection with this series of cases it should be mentioned that not all of them were received at the special hospital direct from the front line. Of the cases with gunshot wounds of the head with penetration of the dura some (116 in number out of a total of 389) underwent operation at a casualty clearing station, and were transferred after approximately ten days. The mortality in these cases was, of course, much lower, as they were the survivors of a far larger number. As will be seen in Table II, the mortality in the first ten days was 38 per cent. in the cases sent direct to the special hospital.

This explains the discrepancy apparent between the total number of cases as given in Tables I and II, with a mortality of 55·7 per cent., and the number of survivors as given in Table III for this class of case. Similar conditions obtained in the other classes.

With regard to the percentages of complications, the results in Table III are given in percentages of recoveries; in Table II, in percentages of the total.

Conclusions with regard to early treatment.

The problem of treating gunshot wounds of the head is similar to that encountered in the wound of any other region, namely, the prevention or diminution of septic infection. Gunshot wounds of the head should in consequence be operated on at the earliest possible moment, and as a rule within twelve hours of the receipt of the wound, but it should be borne in mind that the patients do not stand transport well for a considerable period after operation. Therefore it is necessary wherever feasible to arrange for their treatment at special hospitals near the line where they can be kept for a prolonged period after operation.

All cases with any injury to the scalp caused by gunshot wounds require operation. This should wherever possible be preceded by X-ray examination. The type of operation for penetrating head wounds is one which has for its object the most complete removal of all infected and lacerated tissue. In the case of compound depressed fractures, the depressed bone should in all cases be removed and a complete cleansing operation performed. In no case should the intact dura be incised at the initial operation. All scalp wounds should be excised and the skull must be very carefully examined for fracture. The risk of serious complications in scalp wounds is by no means negligible. This point is far too frequently overlooked in these apparently trivial cases.

A general anæsthetic combined with local injection of novocain and adrenalin is preferable in all seriously wounded cases.

After operation absolute quiet is essential. Large and repeated doses of morphia are indicated if the patient is restless. Patients should be kept in bed for at least five weeks in all cases of severe cerebral injury whether the dura is penetrated or not.

Fits are common in the early stages. It is improbable that they have any serious significance as regards the onset of epilepsy at a later period of convalescence.

Cerebral abscess is the most common cause of death after the thirtieth day.

Mortality is over 50 per cent. for cases in which the dura is penetrated. Mortality in the cases which were operated on, excluding moribund cases, is approximately 45 per cent.

The later Stages of Wounds and Injuries of the Head.

Within a few weeks from the infliction of the wound or other injury most patients will have passed out of the period of immediate danger to life and can safely be moved for such further treatment as is necessary to hospitals at a distance from the front. The care of patients in this second stage of their progress falls naturally, therefore, to a large extent into different hands from those concerned in the early treatment; it raises, moreover, a fresh series of problems in diagnosis and treatment.

In general it may be said that by June, 1920, the number of cases in the later stage calling for further treatment was very large. It is not possible to give even the most general estimate of what proportion of patients treated in the early stage by approved methods needs surgical treatment at a later stage. It is certainly considerable, and probably much greater than has been generally recognized.

The material of this type that presents itself for the consideration of the surgeon may be grouped in certain broad classes.

- (1) Infections manifest or latent.
 - (a) Open hernia cerebri.
 - (b) Persistent sinus.
 - (c) Foreign body.
- (2) Results of mechanical injury of the brain.
 - (a) Destruction of brain substance.
 - (b) Unresolved contusion of the brain, local or diffuse.
- (3) Traumatic epilepsy.
- (4) Openings in the skull.
- (5) Traumatic neurosis.

Infections Manifest or Latent.—The modern treatment of head wounds as defined at the beginning of this chapter has for its objects the prevention of infection by the removal of all potentially infective material and the securing of primary union. Experience has shown that these objects can be attained in a large proportion of cases. When the primary treatment is not successful in carrying out its objects completely, an infection may and commonly does develop. This may carry off the patient as the result of a diffuse meningo-encephalitis, or falling short of this may, after causing an acute and dangerous illness, fall into a state of relative quiescence. During this period the patient may remain for weeks or months without severe or active symptoms, but still showing evidence of continued sepsis in the form of an open suppurating hernia

cerebri or a sinus. Again, the primary treatment may fall short of success in that it has not proved possible to remove all foreign, and therefore potentially infective, material from the wound. A very large number of cases of this kind occurred during all periods of the war. Supposing all other infective material to have been removed, the presence of a deep-seated metallic fragment is by no means inconsistent with rapid recovery and healing by first intention without any serious symptoms. Such a foreign body can never be regarded as unaccompanied by infective organisms even though it may have lain apparently innocuous in the brain for many years. In all these cases with continued or latent sepsis there is the possibility that a cerebral abscess may at any time develop as an insidious or as a fulminating complication.

Open hernia cerebri.—A suppurating cerebral hernia as a chronic condition is almost always ultimately fatal. It is common knowledge that a hernia which has followed upon an infected wound frequently subsides and heals over in a remarkable and unexpected way. This subsidence, however, if it is to occur at all usually begins to show itself in the earlier weeks of the case. If after the clearing up of the acute inflammatory changes in the brain the hernia persists as a chronic and relatively symptomless condition, a favourable result is hardly to be expected. Such a chronic hernia tends to be accompanied by distortion and prolongation of the cerebral ventricle into it, by sclerotic changes in the surrounding brain and by slight infection of the ventricle which tend to keep up the protrusion. Sooner or later, either with or without rupture of the ventricle on the surface of the hernia, suppuration in the ventricle occurs and proves fatal. Treatment is of little value, whether it is directed towards causing shrinkage of the hernia by local treatment of it or towards reducing the intracranial tension by repeated lumbar puncture. This latter may cause some temporary shrinkage of the hernia but cannot be frequent enough to produce lasting effects. Practically the only hope in such a case is that the intracranial tension is being maintained by a cerebral abscess in the neighbourhood of the hernia. Even then the finding and draining of the abscess are likely to be both dangerous and unsatisfactory.

Persistent sinus.—In a considerable number of cases infected wounds have cleared up to the extent of leaving only an inconspicuous and apparently trivial sinus. Such cases are always to be regarded seriously from their liability to be

complicated by latent or very insidious cerebral abscess. Any interference with a sinus of this kind other than a deliberate or systematic open exploration is to be avoided. Before exploration is undertaken careful X-ray examination may be of value in indicating the position of foreign bodies. Most of the persistent sinuses are not due to mere necrosis of the skull, as the surgeon is often inclined to hope, but are associated with infective conditions of the brain and with foreign substances, bone, metal, skin or clothing imbedded in it. Cases of this kind were naturally less common during the later stages of the war than at the time when systematic primary excisions of wounds were not undertaken as a matter of course. The operative treatment of sinuses should include free exposure and removal of bone and the careful following out of the track under the guidance of sight until the cause of its persistence is found and removed. Free drainage of the wound for a time is of course necessary.

Foreign body.—The subject of the treatment of residual foreign bodies in the brain is a very difficult one and does not permit of the laying down of very definite rules for the guidance of the surgeon. The fundamental pathological facts to be borne in mind are two. First, a foreign body must always be assumed to have been the vehicle of infective organisms which may remain altogether latent in the brain for an indefinite period. It is not very unusual for a patient to carry a metal fragment in the brain for two or three years without any symptoms at all and then suddenly to develop a cerebral abscess. There seems to be no limit to the extent of this period of latency. Secondly, a foreign body lying in the brain is usually the cause of a pronounced sclerosis developing in the tissues around it. This makes it much more difficult to find than in a recent wound, and when found much more difficult to remove.

A foreign body—even a considerable piece of metal—rarely produces symptoms as such. When it is near the surface of the brain it seems apt to cause fixation of the latter by the development of peculiarly dense adhesions to the meninges. In such a case serious discomfort may accompany movements, and especially such efforts as cause alterations in the venous pressure.

It is doubtful if the mere possibility of latent infection is sufficient justification for attempting the removal of a foreign body unless it is obviously accessible with ease. If a foreign body is in itself the cause of severe symptoms, if it is associated

with epilepsy, especially epilepsy with a focal onset pointing to the affected region, the question of removal should be considered. The decision will be influenced by the size and accessibility of the foreign body. Evidence of the development of a cerebral abscess would, of course, in itself constitute an indication for operation.

The exact X-ray localization of the foreign substance is a necessary preliminary. Sometimes the best method for the surgeon to adopt will be to cut down upon the metal through the most convenient available "silent" region of the brain independent of the wound of entry; in other cases the track of entry which can usually be felt as a firm cord in the brain substance affords the most satisfactory guide. The metal is usually surrounded by a firm fibrous capsule which obscures recognition by the finger or by instruments and has to be cut through with the knife before unmistakable recognition is possible. This difficulty in making actual contact with the foreign body is peculiar to long standing cases, and one of the worst obstacles to success in removing them. Whenever a foreign body that has been long in the brain is to be removed, the surgeon must be fully prepared for a long and tedious operation, during which all manipulations are restricted by the absolute need for gentleness and deliberation.

Results of mechanical injury of the brain.—Damage to the brain inflicted at the time of the wound has been the cause of persistent symptoms in a very large number of patients. Cases of this kind are divisible into two fairly distinct classes according to the type of symptoms they present. There is a group showing definite paralytic phenomena such as monoplegia, hemiplegia, hemianopia, aphasia or gross mental change where presumably there has been destructive disorganization of the affected region of the brain; and there is a second group in which there are no paralytic phenomena but the symptoms are in the nature of headache, giddiness and various other abnormal sensations referred to the head. In these cases there is clearly organic disturbance of the brain without destructive changes.

Destruction of brain substance.—In most cases presenting stationary paralytic symptoms the condition is obviously due to destruction of brain substance at the time of the wound. The history of the case, showing the immediate onset of the paralysis, and the situation of the wound corresponding with the part of the brain affected, will confirm this diagnosis. The symptoms in such cases show little or no tendency to progressive

improvement after the early stages, and it may be assumed that by the end of twelve months a permanent condition will have been reached in which no treatment can be expected to lead to essential improvement.

Before coming to such a conclusion it is necessary for the surgeon to satisfy himself that the symptoms actually are due to destruction of brain tissue and are not being aggravated by any removable factor. For example, there may be an element of contusion added to and surrounding the disorganized region, the decompression of which might get rid of some of the symptoms. In most cases of the group, however, a large opening will already have been made in the skull and therefore it is not likely that any neighbouring contusion will have persisted unresolved. A more important possibility is the presence of a latent cerebral abscess which may be responsible for some of the symptoms. Before coming to the conclusion, therefore, that in a given case a paralysis is solely due to destructive changes and is permanent and irremediable, it is necessary for the surgeon to satisfy himself of the absence of any such contributory lesion. In the case of a purely destructive lesion the symptoms should be non-progressive, there should be no headache beyond such as may be due to the opening in the skull, and the intracranial tension as shown at the gap in the bone should be normal.

The only case in which a purely destructive lesion shows sometimes progressive symptoms is that of an extensive frontal injury. Here there is often a progressive mental deterioration going on for a long time after the wound, though there is no evidence whatever of any complicating lesion such as an abscess.

Unresolved cerebral contusion.—This is one of the most important of the sequels of head injury and is one of the commonest causes of prolonged disability after wounds which seemed at the time relatively trivial, and after other injuries from which recovery had promised to be complete.

A contused region of the brain is at a disadvantage compared with a contused part of any other organ, in that, on account of the rigidity of its capsule, it cannot swell freely. This restriction of swelling subjects the circulation through the bruised part to a certain embarrassment which hinders absorption of extravasated material and delays recovery for an indefinite period. As long as a contused condition of any part of the brain persists the intracranial space is to a certain extent encroached on, so that there is less than the proper

margin left for the normal movements of the brain corresponding with the arterial and respiratory pulsations. Any physical effect is likely therefore to make manifest the presence of this encroachment on the intracranial space by causing headache. Headache, therefore, is the characteristic symptom of an unresolved contusion, and it is common knowledge that a persistent liability to headache is the commonest and one of the most disabling sequels of head injury.

Headache of this nature is clinically very characteristic. It may be chronic with paroxysmal exacerbations or occur only in attacks between which the patient is and declares himself to be perfectly well. The exacerbations or attacks are of great severity and may last a few hours or several days. They may or may not interfere with sleep and in relatively mild cases the patient finds that the attack lasts through the day on which it has begun and subsides during sleep in the following night. The pain is very severe, of a bursting throbbing quality and is aggravated by movement, mental effort, by light, by noise or any other disturbance. Sometimes the pain is so severe that the patient's mental equilibrium is for the time upset. He is apt to be irritable and resentful under any kind of interference and may even become violent. The attacks are brought on by exertion, excitement or fatigue. The liability to them may disable the patient from following any regular and especially any laborious occupation. Giddiness is also complained of as an accompaniment of the headache and sometimes is a conspicuous symptom.

Headache of the contusion type occurs as a result of either a local or a general head injury. It does not occur in cases in which any considerable area of the skull has been removed, for such an opening has a decompressive effect and allows of the subsidence of contusion. It is typically seen therefore after glancing wounds by projectiles with or without fracture of the skull, in cases which have not been operated on or where if an operation has been done only a small opening in the skull has been made, so that a dense and immovable scar has been able to form in it. Cases of general head injury which develop headache of the contusion type are those in which there has been general deformation of the skull with or without a bursting fracture—the so-called “fracture of the base.” In such cases there is commonly more or less contusion diffusely scattered in the brain and this acts precisely as does local contusion in restricting the intracranial space.

Local contusion does not as a rule lead to the appearance of

persistent headache until the patient begins to get about during convalescence, sometimes not until he takes up active life, but diffuse contusion following injury of the general type usually causes severe headache from the time the patient regains consciousness. This may continue indefinitely or may, after subsiding, relapse if the patient returns to active life too soon.

Local contusion causing severe persistent headache demands operative treatment. This is generally very successful and involves the free exposure of the contused region by a decompressive operation. The opening made in the skull and dura will have fulfilled its function of allowing the contusion to subside within some three or four months and then may be closed. At the decompressive operation definite evidences of contusion may be recognisable several years after the original injury.

In cases of persistent headache following head injuries of the more general type, prolonged rest usually leads to a satisfactory cure. If rest is ineffective or if relapses occur, a temporal decompression is usually immediately effective.

Traumatic epilepsy.—It is not possible yet to state how frequently epilepsy follows wounds of the head, or after what kind of wound, if any, it is especially likely to appear. There is some reason to suspect that wounds which have developed infections are more likely to be followed by epilepsy than are aseptic wounds. Patients who have had Jacksonian fits as symptoms of the early stage do not seem more prone to the later appearance of epilepsy than other patients. As a general rule traumatic epilepsy, if it is going to appear, will have shown itself about six months after the wound. There are no definite characteristics by which the clinical phenomena of traumatic epilepsy can be differentiated from those of ordinary epilepsy, so that the traumatic form is merely to be defined as epilepsy appearing after a head injury.

There is no surgical treatment applicable to epilepsy as such. Since, however, the condition seems to depend on an increased excitability of the brain, operations to deal with any obvious intracranial abnormality may be called for. Epilepsy accompanied by persistent headache occurring independently of the fits is an indication for operation. Dense and bulky scars involving the brain, meninges and skin should usually be excised. In such cases there may already be a paralytic lesion and the surgeon should in general be careful not to increase this by such an operation. Certain cases of epilepsy

in which the incidence of the fits seems to be influenced by mechanical factors such as posture, and in which there is a large gap in the skull with a freely movable scar are benefited by a plastic operation to close the opening.

Openings in the Skull.—It was formerly believed by many authoritative observers that an opening in the skull as such is symptomless, and that the complaints frequently made by patients in whom such an opening has been made are evidences merely of a neurosis. Study of the very large material afforded by war injuries has, however, confirmed the contrary view and shown that an opening in the skull tends to produce a definite train of persistent and disabling symptoms which are undoubtedly of organic origin and are curable by a satisfactory operation.

The symptoms referred to may be altogether absent as long as the patient is kept in bed or is leading a quiet life. They tend to develop with the resumption of activity and gradually and regularly to increase with it. A patient who finds little to complain of while he follows a sedentary and uneventful occupation may be quite unable to take up a mode of life involving physical exertion and exposing him to fatigue. The symptoms that may develop are as follows :—

Tenderness of the Scalp.—This is apt to be felt especially about the edges of the opening. It may be very acute and harassing if it affects a region that is pressed on by a hat.

Consciousness of the opening.—Though there may be no actual pain the movements of the brain at the opening may be very distressing. Every time the patient coughs, sneezes, laughs, strains, stoops or makes any effort the brain is felt bulging into the opening and gives a sense of uneasy discomfort like that due to an unsupported abdominal hernia. Sometimes the patient acquires the habit of supporting the opening with his hand. These sensations, apart from the disability they produce, keep his weakness constantly in the patient's mind and tend to make him disinclined for perfectly safe efforts. Openings in some situations are apt to be unduly exposed to slight accidental blows which are always very alarming to the patient. Openings on the top of the skull seem in general to be more troublesome than openings on the lateral parts.

Headache and other abnormal sensations.—When the intracranial tension is normal and the tissues closing the opening are freely flexible there is always a tendency for a progressive sinking to occur. This may go so far that in a

large opening when the patient is standing up the scalp may be depressed for an inch or more below the surrounding surface. When the patient lies down the depression is obliterated and when he strains an actual bulging occurs. This mobility of the brain through such a range probably influences unfavourably the cerebral circulation and causes traction on the dura. Such traction on the dura is probably the cause of the headache that is so common in these cases. The headache is not usually of great intensity and is quite without the severe bursting quality of a contusion headache ; nevertheless it proves to be very distressing and in combination with the other symptoms often produces a serious disability. It always displays evidence of its mechanical origin. In some cases the normal or bulging position of the brain causes the headache and then the patient complains that he wakes with it in the morning but that it begins to get better after he has been up and about for some time. In others the depressed position of the brain causes the headache which then tends to come on gradually after the patient has been on his feet for some time, while it gets better when he goes to bed. Giddiness and various uncomfortable sensations in the head that are difficult to define are apt to accompany the headache or to occur during stooping or any effort.

Effects on brain lesions.—In certain cases it has appeared that the recovery of damaged brain tissue in the neighbourhood of destructive lesions has been retarded by the presence of a large opening and a mobile scar. Doubtless there is a period during which the recovery of such bruised regions is favoured by a large opening and indeed a free decompression of all contused and swollen areas is often a necessary preliminary to improvement. In the later stages of recovery, however, where return of function is almost complete and where all swelling has subsided the closure of an opening seems often to have a beneficial effect.

Again, in some cases of epilepsy the fits seem to be associated with the mechanical changes that accompany changes of posture ; for example, the attacks may come on only within a short time of the patient having got out of bed. Some of the frequent cases in which the fits always occur when the patient is lying down may be of the same nature. If it is obvious that the opening has completed its decompressive action, benefit may result from closure.

Closure of cranial openings.—It is probable that it will come in time to be recognized that all openings in the skull tend

to disturb the perfect functioning of the brain and should, in the absence of contra-indications, be closed. Definite symptoms caused by the opening and the suspicion that some other condition is being unfavourably affected by it, are adequate indications for the operation. Closure of an opening must be rigid and there are two methods which meet this requirement—the implantation of a moulded celluloid plate and the use of flat bone grafts from the inner surface of the tibia. The latter method was used by Wagstaffe and Trotter and proved to be satisfactory, and in patients seen after several years no defect has been observed. A large scalp flap is reflected including the region of the opening and a wide margin round it. If there is a scar in the skin it is excised and the hole thus made in the flap stitched up. An incision is now made down to the bone at the edge of the gap; the cicatricial tissues in the gap are dissected away from the dura and the latter is detached from the edge of the bone where it is apt to be closely adherent. As far as possible penetration of the dura should be avoided, though if it occurs no harm need result. The pericranium is turned back from the opening in a fringe all round it; the edge of the opening, usually much thickened and sclerosed, is chiselled down so as to present a flat and raw bony surface for the graft to rest on. The inner surface of the tibia is exposed by the reflection of a long narrow flap having its base corresponding with the inner border of the bone and its free edge corresponding with the crest of the shin. Each graft should be long enough to lie across the opening and to rest on the raw bone surface on each side of it. It should retain its periosteum which should be cut so as to project in a fringe all round it. A frame saw having a blade that can be fixed at any angle is used and the grafts cut should be uniform slabs of the whole breadth of the inner surface of the tibia about $\frac{1}{2}$ inch thick and of appropriate length. Tibiæ vary greatly in the width and flatness of the inner surface. As a rule two full width grafts will cover the opening. Sometimes three or even four are necessary. To close a very large opening it may be necessary to draw on both tibiæ. The periosteal fringe of the graft is tightly stitched to the pericranial fringe of the opening until it lies closely and immovably against the skull. The periosteum of one graft is stitched to the periosteum of the graft lying alongside it. No great nicety of fitting upon the skull is necessary but the grafts must be very securely fixed. In time the angularities of the implanted bone are moulded away, and it is often difficult

ultimately to recognize by palpation that there has ever been an opening in the skull.

Patients who have suffered from a cranial defect almost always express what seems even an exaggerated sense of relief after an operation for closure.

Traumatic Neuroses and minor organic injuries.—It does not come within the scope of this chapter to enter upon the subject of neuroses in relation to head injury, but certain remarks touching upon them are relevant here. The war has directed a great amount of attention to the whole subject of neuroses and psychoses and has greatly widened the extent to which their range and importance have been recognized. It is possible that this expansion of interest in the elucidation of symptoms of purely mental origin has to some extent obscured the greatly increased knowledge obtained of the effects of minor grades of organic injury. A very large range of symptoms is apt to follow head injuries without the accompaniment of any of the gross and familiar evidences of organic cerebral injury. Such symptoms—those especially, for example, of slight unresolved contusion and of cranial defects—have too often been supposed to be of a “functional” or “neurotic” origin; whereas, as is now known and largely as the result of war experience, they are as definitely due to organic disturbance of the brain as is a hemiplegia. This subject of minor organic injuries of the brain is of great practical importance since these lesions are responsible for a very large amount of incapacitation during the later progress of cases of head wounds. The restoration of effective function in a damaged brain probably demands an exceptional completeness of recovery. Very slight and apparently trivial disturbances are capable of interfering in a surprising way with satisfactory function. Most of such disturbances are traceable either to the rigid encapsulation of the brain by the skull or on the other hand to this encapsulation being interrupted. In many cases the patient cannot be restored to the normal without this encapsulation being first interrupted for therapeutic purposes and then at a later stage being restored. Altogether apart then from the graver injuries, the war wounds of the head tend to produce a large residue of cases in which a serious degree of disability is associated with a relatively trivial pathological condition. This great group affords abundant and promising material for close study and precise diagnosis and, as far as present-day knowledge permits of the belief, is to a great extent susceptible of effective treatment.

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CHAPTER II.

INJURIES TO THE FACE AND JAW.

BEFORE the war there was comparatively little experience of jaw and face injuries. The most important advance that had been made was the attachment of dental surgeons to the army during the South African War for the express purpose of controlling the mandibular and maxillary fragments in these injuries.

The number of face and jaw injuries that occurred during the war was great. Their frequency was due not only to the very large total of casualties but also to the type of warfare, as trench warfare was much more productive of facial injuries than open fighting. Also the provision of the steel helmet increased rather than decreased the number of these injuries owing to the fact that men hit by one or more pieces of projectile had their lives saved by the helmet, only to be wounded by a fragment on the face.

Shell and other fragments claimed most victims, while bullets, especially in the earlier part of the war, ranked second. The sniper's bullet at short range produced a very different type of facial injury from that of the long-range bullet. The "Verey light" pistol was responsible for a small number of wounds of a very destructive type. The charge entered a man's face at short range with the force of a projectile, and then the rocket, becoming alight, burnt the inside of the facial skeleton in an astounding manner. Very many of these cases developed fatal lung complications.

Secondary projectiles in the form of debris, stone and other materials were also the cause of facial injuries, for the most part of a simple type.

Burns formed the next largest class of injury. Apart from the Verey light mentioned above, the main causes of burns were petrol and cordite. The petrol burn was most commonly seen after aeroplane crashes, but was also met with amongst tank casualties. Liquid fire does not seem to have caused any serious injuries. Cordite burns were met with in gun pits, ammunition dumps and following premature bursts. A large number of these burns occurred also in the navy.

Of other causative agencies of facial injuries the aeroplane crash was the most important. All sorts of severe crushes of the maxilla and mandible were met with in these accidents.

Kicks from mules and horses were responsible for another large section of mandibular fractures, whilst a surprisingly large number of facial injuries occurred during various sports such as football and boxing.

The types of injury produced by these various factors may be classified as follows :—

1. *Injuries of the Mandible.*—(a) Simple type. The simple type fracture was caused by projectiles which produced wounds without serious loss of soft or hard tissue ; by any of the direct blows occurring in aeroplane crashes ; or by kicks and blows. In all respects these injuries conform to the civil injury and its sub-varieties.

(b) Fracture of the mandible with loss of bone but without serious loss of soft tissue. This occurred when projectiles caused comminution of the mandible without carrying away the whole of the jaw or chin. It is comparable to cases of surgical removal of the mandible.

(c) Fracture of the mandible with extensive loss of bone accompanied by serious loss of the soft tissues. A large shell fragment or a short range bullet was usually responsible for this type of injury, and the direction of the projectile was usually at right angles to the sagittal plane.

2. *Injuries of the Maxilla.*—A very large number of simple type fractures was met with in the war, involving either the nasal process or the malar prominence ; the remaining fractures were usually compound. There were three types.

(a) Those above the alveolar ridge involving the antra and the nasal processes, and associated with fractures of the malar-zygomatic ridge. Those including the alveolus were associated with displacement and mal-occlusion of the teeth. This latter type was frequently associated with loss of many teeth.

(b) Severe crushes of all the maxillary and associated skeleton. These occurred in aeroplane crashes. The bony skeleton was crushed and irreplaceable, while the soft tissues were not destroyed.

(c) Fractures of the maxilla with loss of bone and loss of soft tissues. From a treatment point of view these should be divided into those penetrating the maxilla, antra, nose, etc., and those involving the mouth with the alveolar ridge completely or partly destroyed. Associated with the extra-oral fractures were large losses of the cheek, of the nose, and of the eye and eyelids, and, with the intra-oral fractures, losses of the upper lip and cheek.

3. *Malar-zygomatic Injuries*.—These were either of simple depressed fracture type without loss of soft tissue, or of the compound type with loss of bone and soft tissues.

4. *Injuries of the Nose*.—Five types were recognizable, classified according to their appropriate treatment.

(a) Depressed fractures of the nasal bones, of the septal cartilage and nasal processes of the maxilla. Aeroplane crashes, projectiles, kicks, falls and blows were responsible for these.

(b) Total loss of the nose, due usually to the glancing blow of a shell fragment at high velocity.

(c) The bony or upper quarter to half of the nose was carried away in a considerable number of cases by small projectiles and bullets crossing just beneath the eyes. Usually one eye was involved in this destruction. The resulting deformity has been recognized as the "bird beak" type.

(d) When the middle third of the nose was shot away, the remaining tip structures, alæ, and columella, were drawn upwards until the nares looked directly forward, producing the "pug-nosed" type of deformity.

(e) The lower third or half of the nose below the bony skeleton was shot away in an equally large number of cases, frequently without any other facial injury, producing the "Indian mutilation" type.

5. *Injuries of the Lips*.—Injuries of the upper lip were usually associated with maxillary fracture, and with smaller or greater loss of the alveolar bone. The loss of lip might be partial or total. When total, there was always an accompanying loss of the pre-maxillary portion of the bone. Similarly, injuries of the lower lip were usually associated with loss of alveolar bone. The loss might be minimal, as when the lip was split, or it might be partial, or total.

Total loss of the lower lip was usually accompanied by loss of the symphysis and the soft structure of the chin. Such an injury was usually caused by large high-velocity shell fragments; total loss of the upper lip by smaller fragments at high velocity; while smaller losses usually resulted at the exit wound of a small fragment.

6. *Injuries of the Cheeks*.—Apart from superficial wounds the cheeks were often the site of entry of a penetrating, and of the entrance or exit of a perforating projectile. Such wounds were always associated with one or other of the bony injuries already described.

7. *Injuries of the Eyes.*—When an eye was destroyed there was usually an accompanying loss of one or other lid, the socket tissues and some portion of the bony margin, including the superciliary ridge and orbital plates, or of the malar bone. Blockage and infection of the lachrymal apparatus was a frequent complication.

8. *Injuries of the Ears.*—The ears were not often injured by projectiles, but a number of cases occurred in which the pinna was partially or totally destroyed by a glancing blow, the mastoid region, together with the facial nerve, being frequently involved.

9. *Combined Injuries.*—A large number of cases of severe type combined some or all of the foregoing injuries in greater or less amount.

10. *Burns.*—Burns formed a separate class and, for the purpose of treatment may be divided into three degrees: (a) in which the skin surface was not destroyed and therefore regenerated; (b) in which skin and muscle were destroyed; and (c) in which the bony or cartilaginous skeleton was involved.

Most frequently in burns by flame the prominent portions of the facial anatomy, such as the tips of the nose and ears, were the sites of burns of the third degree; the eyelids, eyebrows and lips, of the second degree, while the cheeks might show only superficial burns. In only a few cases of aeroplane burns were the bony portions of the nose and orbital margin involved. Corneal ulceration was found rarely, and destruction of the globe still more infrequently. The extent of the burn differed according to the protective clothing worn. Thus, the cordite burn of a sailor not only showed total facial burn but also burn of the neck and upper part of the chest. The gunner's tunic and steel helmet protected his body in this area, while the airman's burn was typical on account of the protection afforded him by his leather helmet and woollen scarf.

Methods of Examination of Face Injuries.

After inspection and manual examination of the patient, diagnosis should be confirmed or altered according to X-ray findings. Special surgical records should be kept of the exact nature and condition of the injury, in addition to accurate photographs depicting the loss and displacement of tissues and the resultant deformity. For example, a wound of the face

should be placed in one of the five categories already described, and a wound of the lips should be described as "loss of one-third, centre half," and so on.

Displacements of the soft tissues and destruction of the normal contour of the face should be carefully noted. When the face is severely damaged such a description is a matter of considerable difficulty.

The main principle of treatment for all classes of injury being that "normal portions of the face should be replaced in their normal positions at as early a date as possible," it is essential that every effort be made to estimate the extent of tissue lost and contour destroyed.

In all cases of fractured maxillæ, antero-posterior, as well as lateral, skiagrams are necessary, for by this means only are unsuspected fractures with little displacement discovered, such as intra-capsular condylar fractures.

Difficulties in obtaining radiographs of the jaws arise on account of their form, the liability to superimposition of the other half of the maxilla or mandible, and the proximity of the vertebral column, zygomatic arch, and other structures.

If possible, the patient is placed in a sitting posture on an adjustable stool before the end of the X-ray couch. The plate lies on a lead-covered board and the head is steadied in position by sandbags. If it is necessary to keep the patient in the horizontal posture, the use of a lateral plate-holder gives most satisfaction. To avoid distortion of the image the rays are directed from the opposite side through the neck behind the ramus or below the body of the mandible.

An adjustable tube-stand with tube holder capable of independent movement in three planes is required. A means of registering angular movements should be provided on the stand, and horizontal movements should be indicated by a scale. Such an arrangement not only allows for the taking of stereoscopic pictures, but further permits the setting of the tube at any angle required, so that future pictures of the case can always be standardized for position.

The difficulties in taking radiographs of the jaws enumerated above may be overcome by the use of standard positions, each position giving a view of one portion only of the mandible.

These positions are the condylar for the condyle, ascending ramus and angle; the coronoid for the coronoid process; the molar for molar teeth and associated parts; the premolar for premolars and associated parts; and the incisor-canine for the anterior part of the mandible.

For the condylar view the patient's head rests on his ear, so that a line drawn through the pupils of the eyes is vertical. The central ray is inclined at an angle of 60° in the coronal plane below the mandible and at right angles to the sagittal plane. For the coronoid view the patient's cheek rests on the plate. The central ray is directed as for the condylar position. For the molar view the cheek again rests on the plate. The ray is directed at an angle of 75° in the coronal plane and 70° in the sagittal plane, and passes behind and below the mandible. For the premolar view the side of the nose touches the plate. The angles for this region are 80° and 70° respectively. For the incisor canine view the nose is well flattened against the plate and the central ray makes angles of 85° and 70° with the planes referred to above.

If a true lateral view is required for recording injuries of the facial bones, or for localizing foreign bodies, stereoscopic pictures are taken in the usual way by moving the tube 3 cm. to either side of the central point.

For antero-posterior positions a view of the anterior part of the mandible is obtained by the patient's head being fixed in position with the chin and nose pressed against the plate. The central ray is directed from behind forward through a point on the neck three fingers' breadth below the occipital protuberance, and at an angle of 90° .

The view of the posterior part of the mandible, including angles and rami, is obtained in the same position, but with the central ray inclined upward 10° . For the condyles and neck of the mandible the forehead should rest on the plate and the ray be directed as above, but with a tilt upward of 15° .

The maxilla is viewed by the head being bent slightly forward from the vertical and the ray directed upward at an angle of about 10° .

For showing details of palatal fractures, fractures of the alveolar process, foreign bodies in the floor of the mouth and conditions of the teeth, intra-oral films are used.

Anæsthesia in Operations for Face Injuries.

As every hundred cases of severe facial injury may require a thousand operations, anæsthesia is a matter of great importance. It should also be noted that there is a very distinct and serious risk of septic broncho-pneumonia in operations on facial injuries, particularly in those with injuries of the maxilla.

Local Anæsthesia, usually by 1 per cent. novocain, should be employed for all minor operations on the mouth and lips and

also for large plastic operations whenever the personal factor in both patient and surgeon permits it. Some surgeons do not work well with local anæsthesia, and many patients are intolerant of operations under novocain.

For applying local anæsthesia an all-metal syringe, sterilizable by boiling, should be employed. Advantage should be taken of any nerve-blocking that is practicable, such as that of the inferior dental nerve, the infra-orbital, or the dental nerves of the upper jaw. This should be combined with infiltration anæsthesia. If the local anæsthetic is injected intradermally as well as subdermally very efficient and instant cutaneous anæsthesia is produced.

Prejudices, not entirely without foundation, exist against local anæsthesia. A flap or detached piece of tissue, which might otherwise be viable, may become just so much more injured by the infiltration as to determine its death. When adrenalin is employed, as is usual, in conjunction with novocain, the hæmostasis at the time of operation is somewhat liable to be responsible for a post-operative hæmatoma, which is the chief trouble in this form of surgery. Large operations take longer under local than under general anæsthesia, whereas with shorter operations, the reverse is the case.

Local anæsthesia is indicated in trimming and primary suture, dental manipulations, buccal skin grafting, small flap operations in the region of the nose and upper lip, and implantations of cartilage other than the taking of cartilage from the ribs. It would appear to be contraindicated in the presence of dense and painful scar tissue such as frequently occurs in burns, but no hard and fast rules can be laid down.

General Anæsthesia.—The most important points are the prevention of suffocation of the patient during the operation and of post-operative inhalation pneumonia. Whenever possible, intratracheal ether anæsthesia is indicated. The ether must be warmed, and should be given through one of the recognized insufflation apparatus. There is a certain number of cases where intratracheal insufflation is impossible owing to the difficulty of introduction of the catheter. Particularly is this so where the mandibular fragments, having approximated, are pushing the base of the tongue back. It is best here to utilize the sitting position, and to administer chloroform and oxygen through a nasal catheter. Ether can also be used in this way, provided that the pharynx can be packed and Crile's tubes used. Except in the one instance above mentioned, chloroform should be used only in those climates where ether

is too volatile. Gas and oxygen administered through a nasal tube, and supplemented with ether, give in shorter cases a most satisfactory anæsthesia. In longer cases also intratracheal insufflation of this combination has proved of practical use. A convenient refinement of the intratracheal method is that in which the catheter is passed through the nose and then through the glottis into the trachea. This leaves the mouth entirely free to the surgeon, and at the same time avoids all the dangers of inhalation of blood and other matter.

Principles of Early Treatment.

The two most important points to which medical officers who deal with the cases in the first instance must attend are position and hæmorrhage.

In all cases in which the mandible is shot away the tongue tends to fall back, and blood will in the supine position frequently suffocate the patient. In very severe maxillary wounds also blood easily finds its way into the upper air passages and causes suffocation. These disasters can be lessened by keeping patients in a sitting or upright position. If other wounds or circumstances prevent this, the patient should be turned on his face so that the blood does not pass down the pharynx. Hæmorrhage should be controlled where possible. When time and circumstances permit, efforts should also be made to replace the displaced tissues in as normal a position as possible, a procedure which will tend to relieve pain and to reduce hæmorrhage. Semi-detached pieces of mucous membrane and other tissues may easily die from gangrene due to exposure, or to twisting of their few remaining vessels. Coverings are therefore of use in the preservation of warmth.

More accurate treatment is possible at the casualty clearing stations, and as a general rule all wounds of the face and jaws should be excised according to the present-day principles. Driven-in particles of clothing, débris, pieces of bone and teeth should be removed, and the track rendered as clean as possible by a very sparing excision of its walls, but it is imperative that no skin should be cut away.

When the loss of soft tissues is minimal, as occurs in lips and in through-and-through wounds, very good results can be obtained by primary suture after excision; but where the loss of tissue, say in the lower lip, is more than one-third, or where a cheek wound is of such dimensions that the parts are closed with difficulty, the method of primary suture should be directed

towards closing over raw areas, at the same time leaving those parts remaining in as normal a position as is possible. Thus, tags of mucous membrane should be sewn over the raw edge of a lip wound; skin should be sewn to mucous membrane round the remaining portions of a lip or cheek wound; while, after the excision of the wound, stumps of the mandible should be carefully covered by sewing available mucous membrane over the raw ends of the bone to other mucous membrane or even outside skin. In this way a primary excision and a primary suture, leaving the parts in the best position for subsequent repair, are performed.

In addition, the suture and covering of all raw areas enable mechanical appliances to be utilized with greater facility, and to be tolerated with far less irritation owing to the parts not having been drawn together by too strenuous approximation. For example, where the lower lip and symphysis have been shot away, mucous membrane from the lingual aspect of the mandible should be sewn to the freshened edge of the skin on each side. The advantages of this method appeal not only to the surgeon at the front but also to the plastic operator at the base. Long and continued suppuration is minimized, if not prevented, while the dangers of secondary hæmorrhage are greatly reduced. Septic pneumonia resulting from transportation of the cases is also rendered less frequent.

It is advisable to provide temporary inframandibular drainage in most cases of mandibular fracture, and especially is this the case in comminuted fractures in which parts of the bone have been left to regenerate the new mandible. Great care should be taken not to excise viable portions of bone.

In large wounds of the maxilla the same form of excision can be performed, and the knife should not be spared in making free openings between the mouth and the nasal cavity and its sinuses. It is not always possible in this region to avoid a raw granulating area. Again, in regard to the nose, where small portions are shot away and the rest displaced, the latter should be manipulated back into position and skin sewn to mucous membrane around the margins of the defect.

It will be found that very much less in the way of prosthetic appliances will be necessary to retain portions of the face in a normal position if these principles are adhered to.

Concurrently with this surgical excision, dental manipulations, extractions and splinting should be proceeded with. The minimum of a splint or appliance which will retain the parts in position and at rest is the goal at which to aim.

Contraction of Scars.—This is the greatest difficulty with which the surgeon and dentist have to cope in the treatment of face injuries. In the early stages it is caused by undue approximation, by failure to cover raw areas, and by failure to replace bone or tissues in position. In the later stages it is caused by failure of the surgeon to supply an adequate mucous or skin lining to the part to be replaced.

If the principles of early excision and suture of skin to mucous membrane be combined with the later adequate provision of epithelial lining to flaps repairing mucous orifices, there should be no troublesome cicatrices.

Secondary suture is indicated in certain cases where primary suture has broken down, when the wound has had to be reopened, or where it has been impossible to close the edges of the wound at an earlier stage. Certain external supports, such as those used by Kazanjian and Valadier, have their value on occasions; but elaborate splinting, external or internal, without the proper surgical treatment behind it, as indicated above, will lead only to a false sense of having done the most for the patient.

Fractures of the Jaws.—In common with gunshot wounds of other parts of the body, those of the jaws demand immediate treatment, and the earlier this is instituted the better the prognosis both for the life of the patient and for the final cosmetic and functional results. In the early stages displacements are easily corrected; constant movement of fragments is prevented, with corresponding reduction in pus formation and absorption; teeth and foreign bodies may be removed under an anæsthetic prior to pus formation, and without danger of inhalation pneumonia; and increase in individual comfort results in a favourable mental attitude towards treatment.

At the regimental aid post and in the field ambulance the application of bandages is practically all that can be done, but much is possible at the casualty clearing station.

It is now universally recognized that normal occlusion is the basis of treatment in all cases of fracture of the mandible. In cases of small loss anteriorly it may be possible to approximate the fragments with but little change in occlusion. In other cases, whatever the loss, occlusion must be maintained for future closure of the gap by a bone graft.

The union of mandibular fractures is greatly influenced by the presence of teeth in the line of fracture, and this interposition of teeth between the fragments is of much greater importance

in the anterior part of the mandible, where the circulation is deficient, than posteriorly, where the blood supply is greater. Certain authorities regard the extraction of teeth as absolutely contraindicated; but it has been rightly pointed out that the retention of roots and teeth stripped of their periodontal membrane not only retards union but may, by retaining foci of infection, cause bone destruction and non-union. The only place where teeth may be temporarily retained near the line of fracture is in the molar region, where for special reasons it is advisable to maintain the position of the posterior fragment. As soon as union is sufficiently advanced the teeth are removed.

Small fragments of bone scattered throughout the wound should not be removed, and even if considerably displaced should be brought into alignment. The importance of these spicules as ostrogenetic centres is definitely established. The wiring of large fragments to splints has been advocated. In cases of loss of bone, approximation of the fragments with later stretching of the callus while still in a plastic state has been attempted. Considering the good results obtainable by bone grafting, these methods should now be condemned. Where non-union is anticipated, the fragments must be maintained in their occlusal relationships for future osteoplastic treatment, and movement of the mandible permitted to prevent muscle atrophy. In the case of the edentulous posterior fragment, any upper teeth making contact with the fragment should be removed. By this means not only is undue pressure with resultant buccal or lingual deviation of fragments avoided, but mobility is retained.

In contra-distinction to that of the mandible, the basis of treatment for fractures of the maxilla is approximation, for bony contact is necessary when loss has occurred in order to obtain a fixed base for the mandible to function upon. Deficiencies in occlusion and facial contour are corrected by subsequent prosthesis. Drainage is especially necessary in wounds affecting the antra, as these suppurate very copiously, and septic pneumonia is an early and dangerous complication.

For the diagnosis of fractures of the jaw, in addition to the usual physical signs—pain, loss of power, salivation, irregularity in the line of the teeth, deviation of teeth towards the region of the fracture, sub-lingual hæmatoma and cutaneous anæsthesia—resort should be made to gentle manipulation to determine sites of fracture. Confirmation should be obtained by radiographs, and from these the necessary teeth to be removed are determined.

Oral Hygiene.—It is particularly essential in the early stages to render the buccal cavity as clean as possible. Roots, carious teeth and foreign bodies should be removed, the remaining teeth scaled, constant irrigation of the mouth practised, and teeth and gums painted with iodine or picric solution. By such means sepsis is checked, healing accelerated and septic pneumonia inhibited.

Diet.—Diet is also of importance, and appropriate dietaries have been indicated by various authorities.



Fig. 1.

Mandibular Fractures.---Fractures in front of the angle, when single and when teeth are present in both fragments, are splinted in occlusion. (Figs. 1 and 2.) Where the fracture is double, *e.g.*, through both premolar regions, reduction should be accomplished at the earliest possible moment, or union may result with downward displacement of the central fragment. Moreover the tongue is likely to fall back and cause urgent dyspnoea. Where loss occurs and union is improbable, maintenance of occlusal relationships is indicated. (Fig. 2.)

Fractures at the angle, even when accompanied by loss of tissue, may be made to unite primarily by taking advantage of the forward and upward translation of the posterior fragment due to the action of the external pterygoid. The excursion of this fragment may be increased by removing the upper molar



Fig. 2.

teeth on the same side and thus obtaining bony contact. In fractures at the angle with loss of bone and where no union can be anticipated, the tooth-bearing side is kept in position by an occlusal flange, allowing free movement but no lateral deviation. (Fig. 3.) Any upper teeth impinging on the unsplinted fragments are removed.

Fractures in the ascending ramus not involving the joint capsule should be splinted for union. Where prognosis of union is bad or the joint capsule is involved, flanging, as in Fig. 3, should be adopted to prevent trismus.

Except under conditions where it is possible to carry methods of treatment through from the casualty clearing station to a special hospital, early splinting should be of a provisional nature. The use of ligature wire or ready-made appliances such as Angle's bands and arches offers many obvious advantages.

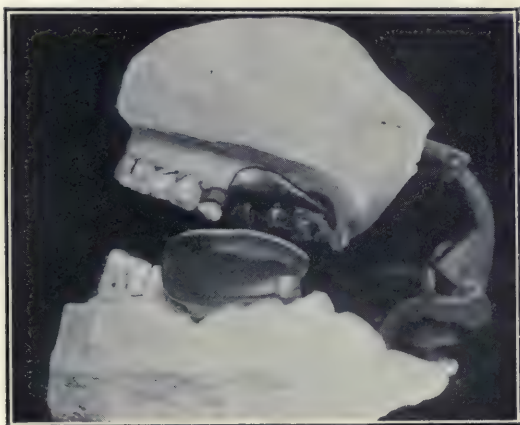


Fig. 3.

Specially constructed splints such as the Hammond and single cap splint may be required. (Fig. 4.) In all cases bandages should be applied; the use of a rubber dam sling is advocated in preference to the four-tailed or Barton bandage.

Whatever splints are employed, they should be such as will maintain fractured bones in correct position, permit of free drainage, be as small as is consistent with strength, and allow of easy removal.

Maxillary Fractures.—These may be subdivided into alveolar, premaxillary, palatine and complete fracture of the upper jaw with or without loss.

In the alveolar fracture, fractured teeth should be removed together with loose alveolar fragments. When many sound teeth are included in a large fragment they should not be removed.

In the premaxillary type of fracture the premaxilla is displaced downward and backward, and reduction should be accomplished as early as possible, for union in malposition rapidly occurs.

In palate injuries the palate should be replaced and maintained in position by means of a removable plate. This serves a double purpose, as it shuts off the buccal from the nasal cavity and supports the palate during healing. Support for the appliance should be extra-maxillary, as illustrated in Fig. 5.



Fig. 4.

In complete fractures of the upper jaw with or without loss of bone, the maxillæ are generally displaced downward and backward, and the injury is frequently complicated by fracture of other cranial bones.

Drainage is the paramount consideration in all cases of fractured maxillæ, and appliances interfering with this in any way should not be used in the early stages.

Combined Fractures of Maxillæ and Mandible.—The necessity for a fixed *point d'appui* must be borne in mind, and some extra-oral support should be used to immobilize the upper jaw. (Figs. 4 and 5.) The treatment of the mandible then proceeds in accordance with the plans outlined above.

If early treatment is carried out on the lines advocated it will greatly diminish the complications and will also materially reduce the time required for subsequent treatment.

Complications.—Immediate hæmorrhage, immediate suffocation and shock are the dangers met with in the field. In the intermediate stages secondary hæmorrhage, suppuration and pneumonia are most likely. There is nothing special in their treatment differing from that of similar complications



Fig. 5.

of other wounds. Concurrently with their treatment the wound as a whole should be reviewed, and an attempt made to place its treatment on a sound basis along the lines already indicated.

One point in regard to secondary hæmorrhage is that, in addition to the adequate exposure of the bleeding point and the track of the missile, it is frequently necessary to tie the external carotid artery.

In the later stages, malnutrition due to serious jaw wounds and continued loss of saliva must be combated by as rich a fluid diet as the patient can take. The patient's mental condition can be greatly aided as regards the depressing effect of continued salivation by "dams," often in the form of a



Fig. 6.

mackintosh pouch filled with some absorbent material. In the later stages also erysipelas and post-anæsthetic fatalities may be encountered. The latter have been rendered almost negligible by intratracheal methods of anæsthesia, and by the use of local anæsthetics where possible. Chronic infectivity may be kept up by a cicatricial contraction of the nasal or buccal airways, a complication which correct early

treatment should not allow to occur. Some few cases of phthisis have occurred among those severe jaw cases in which nourishment failed to be maintained. No case of tetanus from face wounds has been observed.

Late Treatment.

At the special hospital at Sidcup initial efforts were directed towards improving the general condition of the patient. If there had been no early treatment of the case, this was carried out as soon as feasible in accordance with the principles enunciated above. New splints were constructed if necessary.

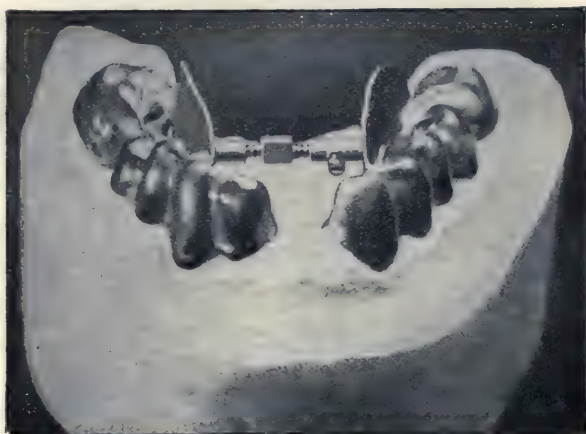


Fig. 7.

Fractures of the Mandible.—In simple fractures of the mandible the single cap splint suffices. In comminuted fractures of the mandible the double cap type, *i.e.*, splints for the upper and lower jaws, was used. These are joined together and the mandible held firmly fixed against the maxilla. (Fig. 6.) Double cap splints may be fixed in either closed or open bite. In the latter position it is claimed that feeding, cleansing and inspection of the mouth are simplified, scar contraction is avoided, ankylosis is prevented, and anæsthetic administration is facilitated.

Against this, however, is the fact that the reduction of the fracture is accomplished on an anatomical articulator, and thus errors are allowed to creep in which cannot occur with closed-bite splints, and that the position is abnormal, that is to say, the parts are not at rest.

Impressions of the teeth are obtained by using small partial trays ; where there is difficulty in opening the mouth, plaster of Paris should be employed. From these models are constructed, and caps of silver or Victoria metal to fit the teeth made by the Taggart casting process. The caps are placed on the corresponding teeth in the mouth and brought into articulation, *i.e.*, displacements are corrected, one fragment being generally occluded at a time.

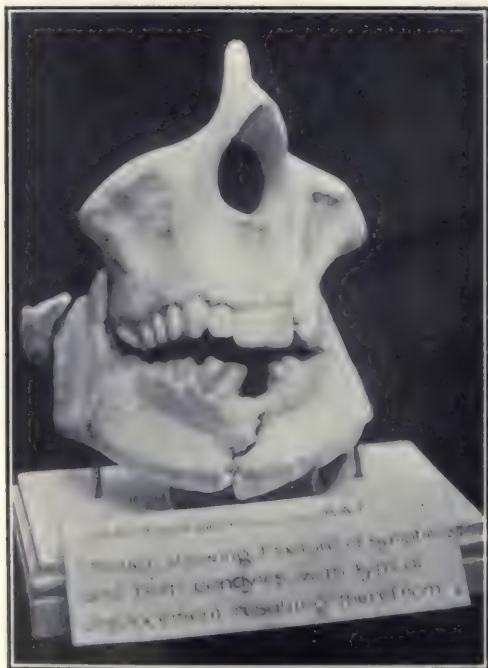


Fig. 8.

Plaster of Paris is then spread over the buccal and labial surfaces of the upper and lower caps. This visible reduction of fragments is an important advance in splint construction.

When the plaster has set, the splints are removed from the mouth, placed in the plaster guides and invested. The individual parts are hard-soldered together, and at the same time horizontal tubes are attached to the upper and lower splints. Screws or taper pins passing into these tubes lock the splints together.

The caps may have their occlusal surfaces removed, but this forces the jaws into tight contact—a condition not occurring when the mouth is closed normally. Moreover, open splints require to be made very much thicker to possess the requisite strength. Finally, the splints are cemented into position with black copper cement.

The mandible should be supported below by means of a chin strap or bandage. It is of advantage in those cases in which there is a large dropped fragment of bone to use a submandibular

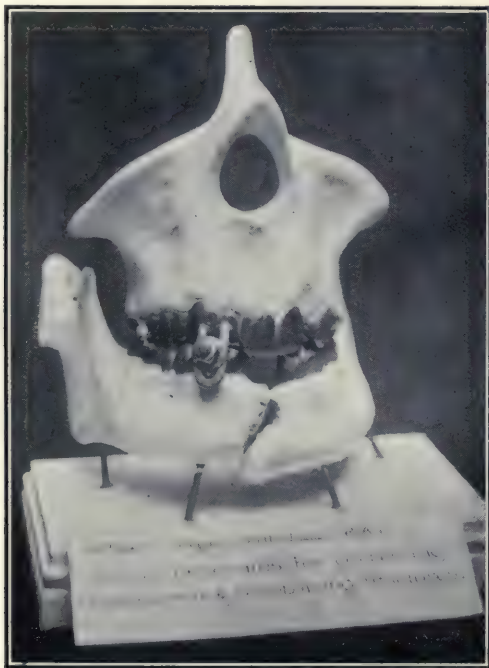


Fig. 9.

appliance to eliminate dead spaces and force the fragments into position.

In old fractures, where considerable delay has occurred between injury and dental treatment, further complications due to malposition of the fragments ensue.

These malpositions are due to impact of a missile, unopposed muscular action, cicatrices and abnormal occlusion. They may be reduced by stretching plates, jackscrew (Fig. 7), wires, silk, or elastic, passing from the upper to the lower splints,

screws acting through loops in the upper splint (Figs. 8 and 9), extra-oral appliances, or surgical measures, *i.e.*, dividing the fragments and bringing them into alignment.

Once the displacement is reduced, if prognosis of union is favourable, the splints are fixed. The influence of use on mandibular fragments is marked, and although in the early stages, and particularly in symphysis fractures, complete fixation is necessary, as union progresses modified function accelerates consolidation. If there is no possibility of union, function of the mandibular fragments should be encouraged, always provided the proper occlusion of the fragments is maintained by denture, flange or splint. This mobilization undoubtedly accelerates bony union and improves the



Fig. 10.

functional result of later operations. In fractures with anterior loss where there are few posterior teeth the hinged denture (Figs. 10 and 11) is useful, for owing to the inward roll of the fragment a one-piece denture is impossible. Where loss is lateral and one fragment is edentulous, or is in the ascending ramus, the tooth-bearing side may have its position maintained by a flange (Fig. 3) or by cranks attached to splints or dentures.

Splints for Bone Grafts of the Mandible.—These should be made especially strong and cemented on the teeth with great care before operation, so that their displacement is difficult. They should be locked with taper-pins to allow of easy separation in cases of anæsthetic difficulties. Guiding flanges should be attached to allow of early movement. The edentulous posterior fragment, if displaced, is difficult of replacement

in correct position by either surgical or mechanical means, and so it is usually advisable to bone-graft it in the position of rest.

Special Mandibular Prostheses.—Where union has occurred with loss of bone, and teeth are present, it may be necessary to construct an over-denture with the natural teeth lingual to the artificial ones.

Where teeth remain on one side only, cribs and stirrup bands (Figs. 12 and 13) are used. Special attachments such as the Roach and Gilmore in combination with indirect retainers have given satisfaction in these cases.

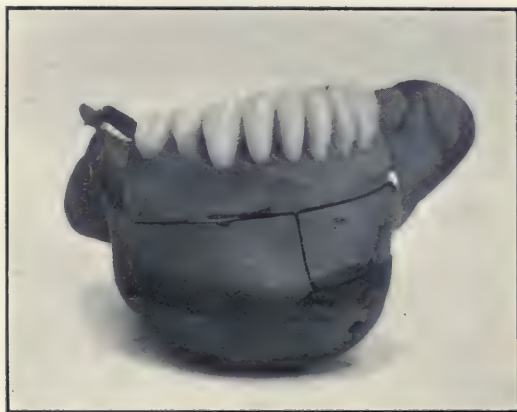


Fig. 11.

Where non-union has occurred with loss of bone and it is inadvisable to perform a bone-grafting operation, satisfactory masticatory appliances are difficult of construction. When the loss is in the anterior part of the mandible and the fragments can be separated a little, a simple denture suffices, for the inward roll of the fragments tends to maintain it in position. When a one-piece denture is contraindicated the hinged variety is used (Figs. 10 and 11). In lateral loss, appliances as in Figs. 14 and 15 have proved of value. When the patient is edentulous and the loss is lateral a double crank arrangement (Figs. 16 and 17) retains both dentures and mandible in correct position. Spiral springs reversed may be used for the same purpose, but their tendency is to displace the lower denture.

Where, for a satisfactory adjustment of dentures, it is desired to deepen the alveolar sulcus, an apparatus is constructed for

the formation of an epithelial inlay (Figs. 18 and 19). The appliance consists of a single-cap splint. At the desired point a vertical bar is soldered to this carrying a flange and vertical

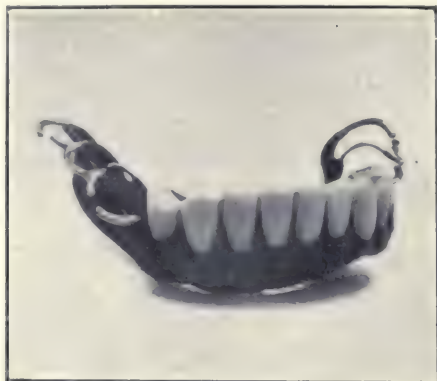


Fig. 12.

tube, the latter slipping over the bar and being locked to it by a screw. The flange retains the model material over which the skin-graft is wrapped in position.



Fig. 13.

Ankylosis of the Mandible.—This is not an infrequent sequel of gunshot wounds of the jaws. It may be due to loss of mucosa, cicatrices of the muscles of mastication, coronoid fixation, true joint ankylosis or prolonged splinting.

Of primary importance in the treatment of these cases is diagnosis ; good radiographs are imperative. Cases due to loss of mucosa are remedied by skin-graft ; those due to cicatrices by appliances illustrated in Figs. 20 and 21 ; while those in which condyle or coronoid are involved require operation and subsequent stretching appliances. When causation is doubtful the forcing open of the mouth under deep anæsthesia is attempted. Wooden wedges are used in the early stages to get sufficient opening and subsequently appliances providing



Fig. 14.

continuous application of force by means of elastic or spiral springs are preferable to those in which opening is obtained by forcible screwing. Such appliances (Figs. 20 and 21) consist of cap-splints for upper and lower jaws with vertical bars soldered at the canine regions, those from the upper splint being diverted vertically downwards, those from the lower, vertically upwards. U-loops soldered on the free ends of these bars give attachment to elastic bands and thus a constant force tending to open the mouth is produced. At first the appliance is worn for four hours daily, the time being gradually decreased as the desired result is obtained.

Fractures of the Maxilla.—The late treatment of fractures of the maxilla differs from the early treatment only in the matter of displacements. Except in cases of alveolar fracture, fixation must be extra-maxillary (Figs. 4 and 5). All losses must be approximated and an attempt made to get a firm basis for mastication.

The usual direction of maxillary displacements is backwards and downwards, and the treatment depends on whether the fracture is impacted or the whole bone has been moved bodily, or whether loss has occurred.



Fig. 15.

When there is definite loss of bone the backward displacement of the maxilla favours union, for with teeth in normal position, that is to say upper teeth external to lower teeth, each movement in mastication tends to separate the fragment; whereas when the upper teeth are lingual to the lower teeth these movements tend to keep the fragments approximated and aid in consolidation.

Opening of the "bite" as a result of downward displacement of the maxilla may be corrected by grinding down or extracting the occluding teeth responsible for this. When

non-union occurs, it is preferable to remove the loose fragment and construct a functional prosthesis. Where there is true impaction of the fracture or bodily displacement of the whole bone, position may be corrected by a Rishworth appliance (Fig. 22), in which the *point d'appui* is both supra-orbital and mandibular. The separation of fragments where there is loss results in the conversion of a probable union into non-union. One case, after being held forward for a year, relapsed in three hours to its original position, the basic principle of bony contact having been deviated from. Union of maxillary fractures in a position of backward displacement causes an



Fig. 16.

ape-like deformity of face. This is capable of correction by separating the soft tissues from the bone, applying epithelial inlays to the raw surfaces, and constructing a suitable prosthesis to keep the soft parts in position.

Maxillary Prosthesis.—Maxillary prosthesis following gunshot wounds may present great difficulties owing to extensive destruction of bony tissue eliminating the structures which allow of denture adhesion and denture stability during mastication. Cicatricial contraction may cause further complications.

In cases of large alveolar loss and extensive adhesion of soft tissues, a new buccal sulcus is formed by means of an epithelial inlay. In cases of large palatal perforations with loss of the pre-maxilla and the major portions of the palatal

processes of the maxilla, the difficulties of retention and stability may be overcome by utilizing the nasal surfaces of the fragments of bone left.

Figures 23 to 26 illustrate a case of this type in which the whole of the pre-maxilla and a large portion of the palatal processes of the maxilla were lost. Sectional impressions were taken with black gutta-percha, firstly of the superior surface of the right fragment, secondly of the superior surface of the left fragment; finally a plaster impression over the maxillary surfaces of these two impressions was taken (Figs. 23 and 24). A three-piece denture was then constructed, one



Fig 17.

piece fitting into the right antrum, one into the left posterior naris, and the third attached to the denture locking these two into position (Fig. 25). Each lateral block has a small metal knob on its inferior surface which gives a definite seat in the upper surface of the denture for the convenience of the patient; on their mesial aspects are horizontal slots into which fits a piece of metal attached to the locking piece. This latter rotates on a central pivot, one end of which projects on the palatal surface of the plate, and the appliance is locked or unlocked by half a turn of the special screw key illustrated. The case is seen completed in Fig. 26. Resistance to upward

stress during mastication is provided for, and displacement of the denture is obviated by the locking of the denture between the superior and inferior surfaces of the bone.

Plastic Repair of Special Areas.

The indications for facial repair are loss of function and disfigurement. Restoration of function is always the primary aim, but if the surgeon can see his way to improving the appearance as well, so much the better. The only cases in which cosmetic outweigh functional considerations are those where the mental condition gives cause for anxiety.



Fig. 18.

The ideal in choosing the type of repair is restoration in kind, *i.e.*, bone for bone, cartilage for cartilage, and so on. With the exception of the eye and the teeth this ideal can be obtained under favourable circumstances.

Lost skin and fat can always be replaced, and as a general rule this is undertaken. The restoration of lost movement is obviously limited, but subcutaneous muscle swings have been employed with a certain measure of success, and there are indications that this branch of repair is only in its infancy. Frequently a compromise is made, such as shortening of the lower lid in facial paralysis.

With regard to the facial skeleton, losses are reparable in kind, with the exception of the maxilla. In practice, the repair undertaken usually consists partly of surgical and partly of

mechanical restoration, the latter by the use of prosthetic appliances.



Fig. 19.

Prostheses are of two main types—those which are introduced into the tissues, “interstitial,” and those which are not and which may be called “external.”



Fig. 20.

Under interstitial prostheses are classed paraffin injections, and paraffin, cellulose and metallic blocks. Experience of these so far warrants rather their condemnation than their recommendation. External prostheses are of two kinds,

superficial" (*i.e.*, taking part in the formation of the facial surface) and "supporting." Superficial prostheses, except in the case of the eye, are an admission of failure. Supporting prostheses are in constant use, and are referred to in greater detail below.

Plastic work should not be commenced until the tissues have completed their reaction to the injury. The duration of this period varies with the degree and type of the original injury and with the efficiency of the individual response, but as a general rule it may be laid down that three months at



Fig. 21.

least should be allowed for this process, assistance in the way of drainage, massage, etc., being afforded where necessary. In the case of gross lesions of the jaws it is advisable, if a bone graft is to be employed, to allow six months.

In this connection severe burns of the face form a class apart. Contraction of the scar tissue, which is usually keloidal in type, continues for many months, and it is sometimes advisable to postpone the major repair for as long as two years. Early local interference, however, is indicated in special

regions with a view to the maintenance of vital functions. Impending danger to the cornea must be warded off by relieving ectropion, even though a repetition of the operation may be looked forward to; and microstoma and stenosis of the nares must be overcome as early as possible.

It is also essential to stop the flow of saliva in jaw injuries, for the loss of vitality resulting from this is astounding.



Fig. 22.

Certain preliminary investigations are essential before plastic operations are undertaken. The patient must be proved free from any active syphilitic taint, and must be in the best possible condition to withstand the combined strain of the operation and the anæsthetic.

The circulatory and excretory functions are examined, and the local condition is scrutinized for minute foci of infection such as acne pustules. If any suspicions are entertained as to latent sepsis in a scar it is subjected to a few days' course of massage and an application of X-rays; this procedure usually establishes its innocence or the reverse.

Plastic Operations for Injuries of the Mandible.—The late treatment of mandibular injuries, like the early treatment, is undertaken as a joint surgical and dental measure. Conditions requiring treatment are non-union and occasionally mal-union. If there be bony loss, in the vast majority of cases a bone graft is indicated, though in certain cases the ends are so firmly splinted by scar tissue that mastication of a type satisfying the patient's requirements can be attained by dentures alone. Cases have occurred where the body weight was maintained on hard manual labour by this means.

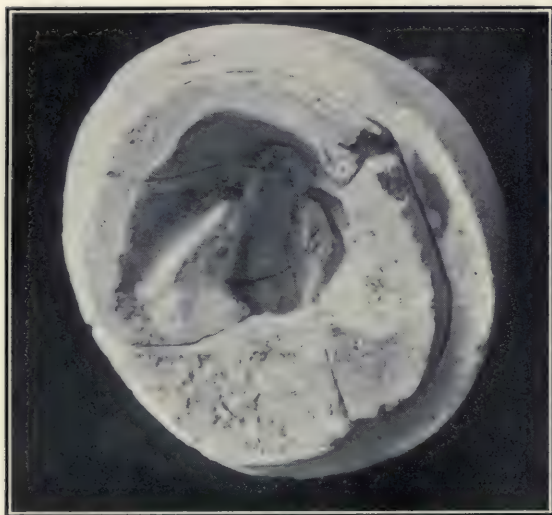


Fig. 23.

Mal-union necessitates re-fracture and a bone-graft when dental occlusion has not been obtained even on one side. The case typical of this is one in which there has been symphyseal loss followed by approximation of the ends, leading to a shortening of the arch. No denture can overcome the mechanical *impasse* brought about by this well meaning effort at early treatment.

Mandibular bone grafting has undergone an evolution not differing much at the various special hospitals. The source of the graft usually chosen to begin with was the rib, because of its accessibility; in certain cases it was satisfactory in spite of the pain resulting from the rib operation. Next in order, the tibia was resorted to, shaped blocks being tried and discarded because of their brittleness, in favour of thin flexible

plates consisting of the periosteum and the under-lying compact bone. This method originated with the French and is still employed where the loss is minimal or where it is so great that it is difficult to obtain from any source a rigid graft of suitable size and shape. An interesting by-path in the search for the best graft was Cole's so-called "pedicle-graft." The source was the anterior mandibular fragment, the graft being taken from the inferior border and slid over the gap, still attached to certain of the depressor muscles. The method was discarded as offering no particular advantages, and as often giving a poor cosmetic result.



Fig. 24.

Finally resort was had to the crest of the ilium, the idea being of German origin, and this bone has been found the best in the vast majority of cases. The material is easily fashioned to the desired shape; a large endosteal surface can be obtained by "stepping" the graft; and the missing contour of the mandible can be exactly imitated by choosing the right part of the crest. The acme of elaboration and result with this method has been obtained by Chubb, who has shown that extreme care in the shaping of the bony surfaces, ensuring perfect immobilization, is justified by the shortening of the period during which splinting is necessary.

In a case of loss and non-union in the molar-premolar region, it is essential to recognize the importance of the early treatment. While the fragments are still mobile the dental surgeon must, by means of splints and flanges, bring the fragments into their correct anatomical position. It should be noted, however, that all such appliances should be dispensed with as soon as position can be maintained without their aid.

If lack of teeth or of a *point d'appui* forbids the application of suitable splints the fragments must be kept mobile, the formation of scar tissue between the fragments and, most important of all, cicatrisation of the mucosa being prevented by sewing mucosa over the exposed ends. With the help of X-rays, a model should be made of the remains of the mandible,



Fig. 25.

and the shape and size of the missing portion reproduced in metal, so that the latter may be boiled and used as a guide at the operation. The incision should begin in the sulcus posterior to the ascending ramus, inferior to the attachment of the anterior border of the lobule of the ear, and pass downward below the horizontal ramus to end under the symphysis. This allows the necessary wide exposure and leaves a scar not obvious after healing.

The bony ends are defined, any scar tissue removed and a good two inches of the outer and inferior surfaces of the fragments are bared of periosteum. The model is then laid on the gap and the fragments separated forcibly until it can be fitted between their freshened ends. This separation is only possible when scarring of the mucosa has been prevented by good early treatment. The graft is then cut, and "stepped"

if the fragments be thin, so that a good overlap is allowed beyond the length of the model, the outer table of the fragments being cut away to fit the graft and *vice versa*. The graft and fragments are drilled and firmly wired with stout silver wire. The splints are retained until union is established, usually not more than three months, but the mandible is released from its fixation to the upper teeth and gentle movement allowed after about three weeks.

The problem would appear to be merely one of aseptic carpentry, and countless published successes in grafting have tended to obscure the fact that the aim of the surgeon should



Fig. 26.

be to enable the patient to masticate, usually by means of a denture. This cannot be obtained unless dental occlusion on at least one side is ensured. The insertion of a graft which is smaller or larger than the missing portion, effectually prevents normal occlusion, and therefore does more harm than good.

A corollary to bone grafting of the mandible is the "epithelial inlay," the method employed being a modification of that practised by Esser. Owing to the obliteration by scar tissue of the external alveolar sulcus, which occurs as a result of the injury, it is usually impossible to fit a satisfactory denture after a bone graft. It is necessary to reconstitute the sulcus by excising the scar tissue adhesions and skin grafting the resulting raw area.

The dental splint required for the operation has already been described. The details of the method are as follows:—

All offending scar tissue must be excised, and the knife must be kept close to the bone, so that no loose soft tissues remain on the alveolar wall of the sulcus. An impression of the new sulcus is taken with warm "Stent," which is made to distend the cavity. When set, this is adjusted to the dental splint. It is then taken out and completely covered with a large, thin, evenly cut Thiersch skin-graft, deep surface outwards, and is pressed firmly into the raw sulcus, and there maintained for ten days by the splint. Meanwhile the dentist prepares his appliance, and must be ready to fit it the moment the Stent is removed, as the cavity is liable to shrink if left unoccupied for any length of time. As an intermediary stage between the Stent and the final appliance, a mould of black gutta-percha is sometimes used.

In cases of gross damage, where the depressor musculature is destroyed, a good functional result cannot be obtained, but, short of this, useful mastication is the rule.

Plastic Operations for Injuries of the Maxilla.—Simple fractures of the maxilla usually involve the malar process, the zygo-malar arch or the nasal process. The outstanding result of all is a depression of this region of the face. Since the principle of replacement of the parts in their normal positions is difficult here, the method used is a restoration of the missing contour by the addition "subcutaneously" of fresh tissue, such as bone, cartilage, muscle or fat. The contour is restored upon the patient's plaster cast by building up by Stent or wax, and the shape of added material is reproduced in metal for use as a guide.

Bone-grafting in this region is satisfactory and if the loss is not too great is the method of choice. Cartilage is not satisfactory, as it is rarely possible to ensure its fixity, but it may be combined with any of the other methods on occasion. The insertion of fat-grafts often gives good results in small losses, but a variable degree of absorption usually occurs, making it difficult to assess the amount required. By a more complicated method, which has been utilized with great success, a portion of the temporal muscle is swung forward subcutaneously with its blood and nerve supply intact; this not only fills up the gap, but, in virtue of its contractility and tone, gives expression to the region in which it lies.

Practically all the remaining fractures of the maxilla are compound. Those of the alveolar ridge call for dental

treatment, those above the ridge involve the antrum, and call for intra-nasal treatment.

In the fractures resulting from aeroplane crashes, the anterior fragment, consisting of the greater portion of the body of the bone, is often displaced downwards and backwards. Replacement in the normal position is achieved without delay by means of the apparatus already described, and where the



Fig. 27.—Condition when suppuration ceased and skin edges have been united to mucous membrane around the aperture.

internal maxillary artery is not obliterated, and provided there is no antral infection, union may result. Non-union, however, is not uncommon, and removal of the fragment becomes necessary. The remainder of the treatment resembles that described below, where the loss of bone is large.

Of fractures with loss of bone and soft tissue, those above the alveolar ridge are usually small, involve the nasal cavity, and not infrequently cause a fistula of the antrum. The first essential of treatment is to ensure intra-nasal drainage of the

antrum, and to free it of polypi, even at the expense of the loss of its lining. If the external opening be large enough, such loss of lining can be made good by skin-grafting, after which the fistula is closed by skin-flaps. Provision for the lining of the covering flap is first made by turning skin and epithelialised scar tissue flaps, surface inwards, from the margins of the defect. The resulting raw area is then covered by a skin-flap from the forehead or chest, as described below, and illustrated in Figs. 27 to 30.



Fig. 28.—Diagram of the reconstruction.

Where the loss is large, the replacement of the bony support is an urgent necessity from the point of view of mastication. The soft tissues have usually fallen in and are adherent to the remains of the facial skeleton (Fig. 31). Under intra-tracheal anæsthesia the soft tissues are freed, and an impression of the cavity thus produced is taken in Stent, and the cavity is lined with skin by means of an epithelial inlay, as already described. Into this non-sensitive cavity is fitted a prosthesis bearing teeth, retained in position partly by its shape and partly by the support of any remaining teeth. Such a prosthesis is a typical example of the "supporting" variety. Its effect is illustrated in Fig. 32.

Plastic Operations for Injuries of the Nose.—Depressed fractures of the nose are treated by immediate elevation into position and retention by means of an appliance placed upon the upper teeth.

If the case comes for treatment late, it may be possible by refracture to remedy the defect on lines similar to those used for early cases. If this is not considered feasible the contour is restored by the insertion, subcutaneously, of a cartilage



Fig. 29.—Shows the tube pedicle lying on the cheek.

graft, the size and shape of which are determined by preliminary work upon the patient's plaster cast. The cartilage is obtained from the fifth to ninth costal cartilages according to the amount and general shape of the piece desired, a vertical incision being made through the skin and rectus, usually over the seventh cartilage, and a piece of cartilage removed with a knife. If the whole depth of the costal cartilage be required, care must be taken not to injure the terminal branches of the internal mammary artery. Post-operative pain is sometimes severe.

The graft is removed to a side table and there fashioned with a scalpel upon a boiled board, being gripped carefully with a gauze swab, as it is very slippery. A curved transverse incision, with the concavity either up or down, is then made in the glabella region, and with suitably shaped knives and tenatomes the skin is undercut, if necessary right down to the tip

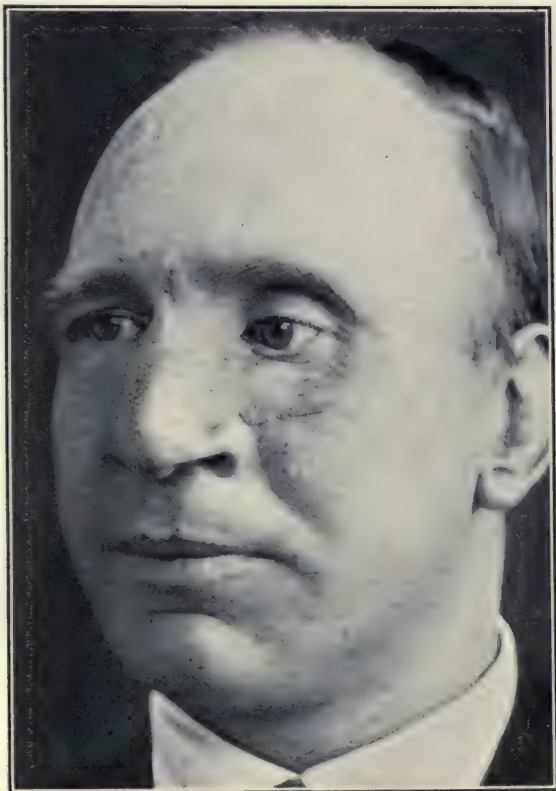


Fig. 30.

of the nose. The forehead and upper edge of the incision are then covered with gauze, and the lower edge of the incision lifted forward by means of a delicate hook. The graft is then inserted from above.

Fixation is obtained by manœuvring the upper end of the graft into a little sub-pericranial pocket and there suturing it, if necessary, with catgut. The wound is closed with horse-hair sutures and hæmatoma formation avoided by pressure

in the form of Stent, applied warm and strapped or bandaged on when set. Any remaining cartilage is stored in the subcutaneous fat of the upper abdomen, in case of the possible need for it elsewhere later.

Where there is total loss of nose the interior of the nostrils must be rendered healthy before plastic work is begun, and any impairment of the airway remedied. Meanwhile, the



Fig. 31.—Extensive bony loss.

surgeon and the sculptor co-operate in designing the nose by careful work with wax flaps, plasticine, etc., on the patient's plaster cast.

Where there is loss of the nasal bones—pre-maxilla, nasal spine, maxilla, etc.—rhinoplasty does not result in a natural looking nose unless such loss is first made good. This is usually done by a supporting dental prosthesis.

The operation is usually divided into three stages; preparation and subcutaneous insertion of cartilage grafts to

form the scaffolding of the nose, followed in three weeks by the rhinoplasty, and, after some further three or four weeks, by returning of the flap pedicle.

The principles of replacement in kind are well illustrated in rhinoplasty. There is loss of lining membrane, scaffolding, and covering skin. The lining membrane is replaced by turning

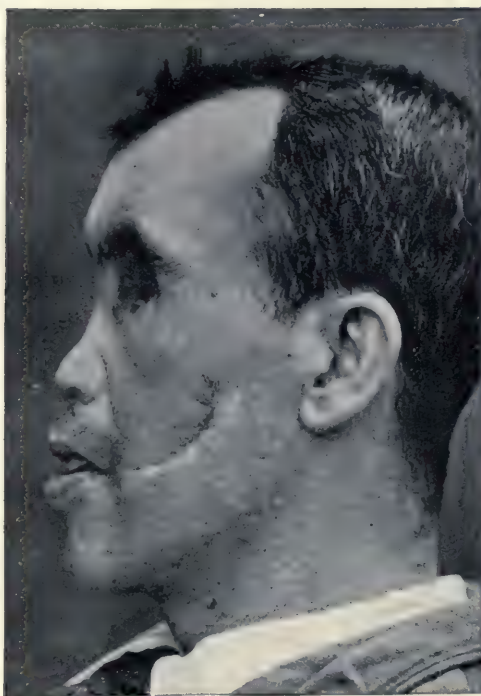


Fig. 32.—Prosthetic replacement of loss.

skin flaps, surface inwards, based on the border of the defect. Surface epithelium is found to form a very good substitute for mucous membrane. The scaffolding is formed of cartilage grafts inserted subcutaneously and swung downwards or inwards with the lining flaps, to which they have previously been allowed to form attachments.

The covering is formed of a skin-flap taken from the forehead, and based either on the glabella or on the temporal region (Fig. 33). Figs. 34 to 37 illustrate, in greater detail, alternative methods of forming the columella.

Plastic Operations on the Lips.—Upper and lower lip injuries seldom occur without injuries to the underlying bones, and the ideal of treatment is to repair the bony loss first, and then build up the lips on the scaffolding so formed.

In practice, however, it is very often found necessary, from the point of view of aiding deglutition or of preventing a continuous drain of saliva, to repair the lips as early as possible.

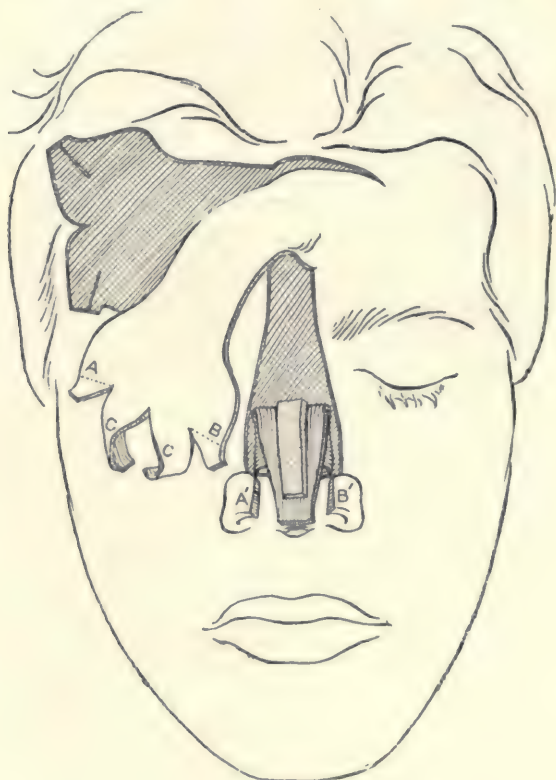


Fig. 33.

The principle of accurate qualitative and quantitative diagnosis, followed by repair in kind, applies here as elsewhere. To make an estimate of the amount of tissue lost it is often necessary to reconstitute the wound. For example, a patient frequently arrives for treatment with the remains of the upper lip drawn together and lying tensely across the upper incisors. The first step is to undo this well-intentioned effort at repair by

excising the scar tissue connecting the lip remains. The gap thus made at once widens, and the diagnosis can be made of the amount of loss in each layer of the lip.

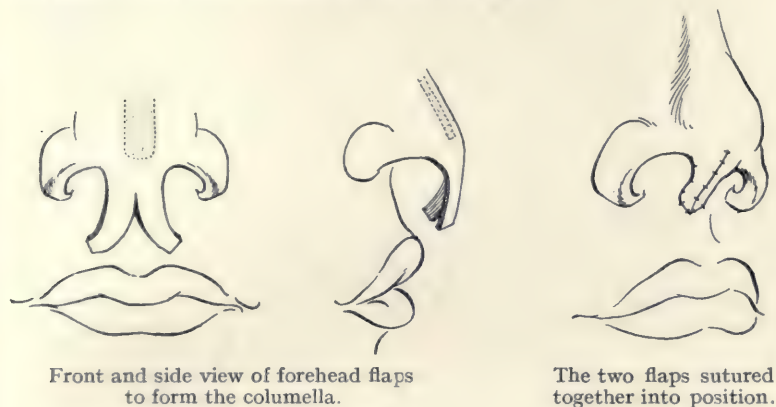


Fig. 34.

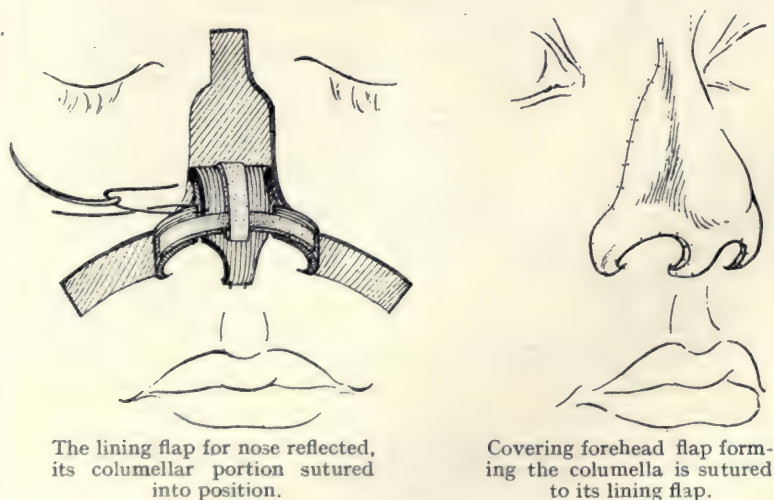


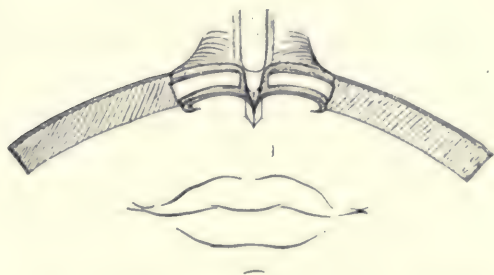
Fig. 35.

If it is not proposed immediately to restore the missing portions, skin is sewn to mucous membrane over the ends of the lip stumps to prevent ulceration with subsequent scarring. The surgeon then has a choice between attempting repair from the neighbouring facial tissues and of going further afield and bringing a flap from the chest or forehead.

As a rule, the lining is made by using mucous membrane flaps where there is mucosa to spare, or by turning flaps, skin surface inwards, from the margins of the defect. The question of covering is a thorny one, some surgeons much preferring to use local flaps, while some pin their faith to skin brought



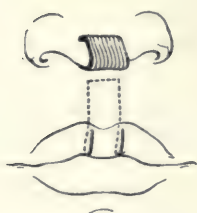
Covering flap sutured to alæ and to columella.



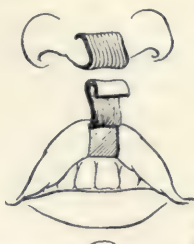
The two lining flaps forming the alæ, with their ends sutured into position to form the columella.

Fig. 36.

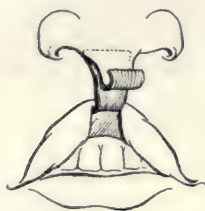
from elsewhere. Good results have been obtained by both methods, and neither is to be laid down as applicable to every case. The chief advantage of local flaps is that they can be designed occasionally to contain muscle which will function in its new position (Figs. 38 and 39).



(a) Outline of incision from the vermillion border to vestibule of upper lip, and the reflection of covering forehead flap to form the columella.



(b) Reflection of mucous flap to form the lining for the columella.



(c) The mucous lining flap and the covering forehead flap in position to be sutured.



(d) The two flaps now adherent. Division of mucous-lined columella from lip.



(e) Columella sutured into position.

Fig. 37

Where the loss comprises the symphysial region of the mandible, the covering skin is brought from the forehead or scalp, the lip repair then being bound up in the larger restoration (Figs. 40 to 45).

The red margin of the lip may be simulated by mucous membrane flaps brought over the lip margin from the lining of the cheek or of the opposing lip. The latter method is clearly illustrated by Figs. 46 to 49. In some cases a small tubed pedicle has been used for this purpose.

Scars.—The scars met with are usually depressed and often adherent to underlying bone; furthermore, they often mask a considerable loss of skin. The scar tissue is excised completely, and if a large gap then occurs the loss is made good

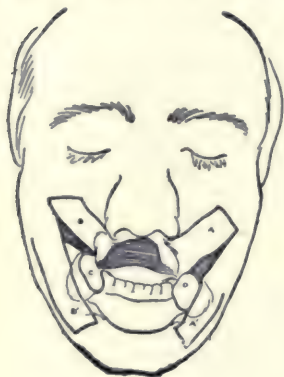


Fig. 38.—The incisions.



Fig. 39.—Suture of the turned in and mucous flaps.

by a skin flap. Where the loss is mainly of subcutaneous fat, the contour is restored by bringing fat-flaps, based either on the skin or on the deeper tissues, from under the neighbouring skin, and sewing them with catgut under the line of the scar. Free grafts of fat are occasionally employed, and with careful asepsis they are often successful, but allowance has to be made for a variable degree of absorption.

Granting asepsis and care in opposing the margin, the chief factor in the production of the least visible scar is absence of tension on the edges of the incision. The sutures should be of elastic material—horsehair is in routine use—and should be taken out very early. Ten hours is the earliest that has been attempted with success. The subcuticular suture is of undoubted advantage if the incision is in a straight line and lies wholly in the same plane.

Flaps.—It will serve no useful purpose to give a list of the flaps used in routine plastic work. They have been described in detail in many text books. During the war, however, an advance in methods of skin transference has taken place which has vastly improved the technique, and has rendered practicable the removal of skin from almost any part of the body to any other part.



Fig. 40.

Hitherto flaps of the imbedded type have been used because of the exposure of raw surface necessitated by flaps which bridge over gaps. Inflammation followed such exposure, jeopardizing the life of the flap, and this was followed later by shrinkage and bunching of the skin employed.



Fig. 41.—Flaps for lining of new chin outlined.



Fig. 42.—Lining flaps being inturned over a prosthetic chin. Forehead flap outlined.



Fig. 43.—Covering flap for chin being swung down from forehead.



Fig. 44.—Suture. Pedicles tubed.

To overcome these difficulties, the edges of the flap were sutured together, making a potential tube of the flap pedicle, and thus preventing the exposure of any raw surface. This form of flap remains supple, and by the development of anastomoses in its substance, a blood supply is engendered of an



Fig. 45.

elasticity and mobility resembling that in normal skin. The variety of application of this principle is endless. The tubed pedicle-flap can obviously be utilized as the vehicle of any of the less highly specialized tissues. It has, on occasion, been used with success to convey a large portion of the scaffolding,

covering and lining of the nose from where these had been slowly built up on the chest to their final destination. Its chief application is in the transference of skin and fat from chest to face in cases of extensive facial burns (Figs. 50 and 51). Hair-bearing skin has also been conveyed by this means to form eyebrows or moustache (Figs. 52 and 53).

Skin-grafting.—The most important factor in Thiersch grafting is apposition between the graft and the receiving surface. Granted apposition and immobility between the raw surfaces, a Thiersch graft can be applied to the raw surface of any tissue except cartilage, or to healthy granulations.



Fig. 46.—Mucous flap from upper lip outlined.



Fig. 47.—Mucous flap swung from upper to lower lip.

This apposition is usually obtained by the help of wax composition moulded for the purpose while hot, and bandaged or sewn into position when set. The type example is the epithelial inlay.

In the use of Wolfe or "whole thickness" grafts, apposition again is of extreme importance. A trace of blood-clot between the grafts and the grafted surface will prevent union. Other factors of importance are careful suturing, a degree of tension comparable with that obtaining in the region whence the graft is taken and immobility for seventy-two hours. Where satisfactory pressure-dressing can be employed, *e.g.*, the forehead,

successes up to 90 per cent. may be expected from Wolfe grafting; the corresponding figure for autologous Thiersch grafts is 100 per cent.

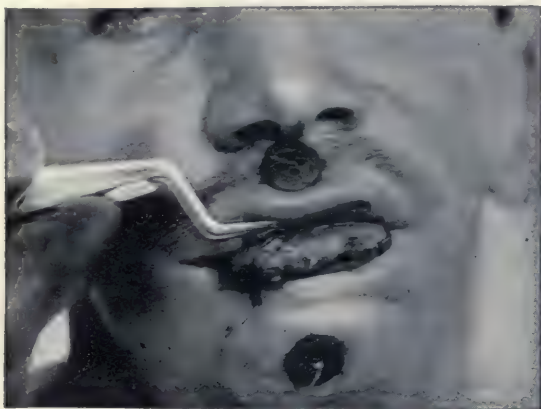


Fig. 48.—Mucous flap from upper lip applied to lower lip.
(Patient fed through a tube in corner of mouth.)

The final appearance of skin-grafts on the face leaves much to be desired. They are often pigmented, sometimes rugose,

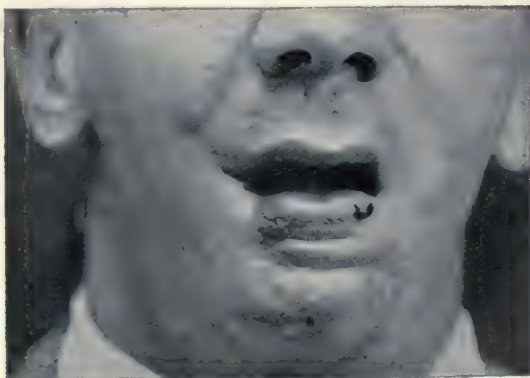


Fig. 49.—Final, showing new vermilion border for lower lip.

and occasionally hirsute even when taken from areas apparently free from hair-follicles. For these reasons flaps are used where possible in preference to grafts.

Plastic Operations for Injuries in the Region of the Eye.—Losses of portion of the bony orbital ring are remediable in three ways. It is often possible to fill a small gap by a bone graft, and this is the method of choice, for by it alone is the rigidity of the framework restored.

If the loss is mesial the repair is bound up in the rhinoplasty which is then always necessary, the missing inter-orbital



Fig. 50.

prominence being restored by swinging down from the forehead a previously inserted subcutaneous cartilage graft.

It is possible to ensure that the lachrymal secretion shall leave the orbit by a skin-lined improvised nasal duct. If this procedure is impracticable the lachrymal gland on occasion may be permanently atrophied by X-ray treatment or may be excised.

In the very common loss of the lower and outer portion of the ring, a bone-graft being rarely practicable owing to the proximity of secreting conjunctival remains, recourse is made to restoring the absent contour by swinging forward subcutaneously the anterior half of the temporal muscle. A horseshoe-shaped skin-flap is turned down from over the muscle and with the help of an oblique incision over the malar



Fig. 51.

remains the muscle-flap is manœuvred forwards and mesially, its extremity being secured to the region of the inner canthus by catgut. Its blood and nerve supply are unharmed by this proceeding and the transplanted muscle contracts on closure of the mouth and so lends a certain amount of expression to this region of the face.

It is often necessary to add to the bulk by the insertion, at a later date, of suitably fashioned cartilage-grafts, but the

impossibility of permanently fixing these to bone detracts from the stability of the result.

A shrunken socket is a common result of gunshot wounds of the orbit, and the condition precludes the fitting of a suitable artificial eye. If the integrity of the lids offers promise of a



Fig. 52.

cosmetic result, the fundus of the conjunctival cul-de-sac is incised and deepened by the removal of scar tissue till its capacity is adequate. The permanency of this raw pouch is then ensured by lining it with a Thiersch graft, which is wrapped, raw surface outwards, about a Mule's globe or a mould of Stent's composition, in the manner of the Esser inlay. The lids are sewn over it for some five to ten days, at the end of

which time the mould is removed, the cavity washed out and any redundant skin cleared away. For three months this skin-lined cavity is never left undistended; thereafter its capacity does not alter. In it an artificial eye is well tolerated, though conjunctival remains may maintain a slight mucopurulent discharge for many weeks.

Where the loss of an eye has been accompanied by orbital damage, movement of the artificial eye has, in some cases, been achieved by the following more elaborate procedure

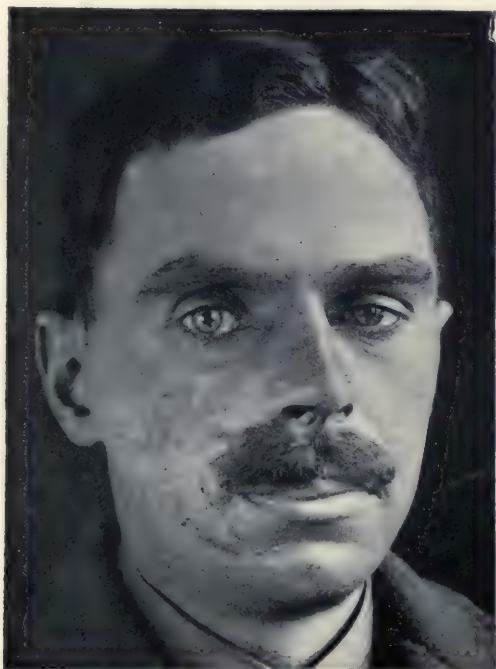


Fig. 53.—Pedicule returned. Moustache grown. Note: The hollow in the cheek was filled by a free fat graft and excision of scar at a later stage.

An autologous cartilage globe is inserted through an incision in the fundus of the socket, and to it the ends of the ocular muscles are sutured in their normal situation. This permits of a large range of movement of the now bulging fundus of the socket, and an artificial eye takes up these movements in a very natural manner. In one or two cases a cup and ball were fashioned from cartilage and inserted in this manner, with sufficiently satisfactory results.

Unless there is a hope of fitting an eye which shall resemble the normal very closely indeed, these operations on the socket are, however, contraindicated. A very small defect in either lid-edge, particularly the upper, usually leads to an appearance so unpleasing that it is better hidden with a "patch."

In cases also of extensive loss of orbital fat, it is rarely that the repellent effect of "sunkennes" has been overcome. Progress in this direction is, however, being made by the use of fat and cartilage grafts.

Injuries to the lids seldom occur alone but usually complicate more gross damage. Provided that the lid-edges are intact, loss of tissue can usually be made good. Lost skin is replaced by swinging local flaps, sometimes by a modification of Tripier's operation. Loss of palpebral conjunctiva, if the eye is missing, is replaced by intumed skin-flaps, but if the eye be present, skin is not tolerated by the cornea and recourse must be had to restoring the missing lining by manipulating the redundant conjunctiva of the fornix region.

In one case such lining was sought further afield, a flap of mucosa from the homo-lateral upper labio-gingival sulcus being brought up subcutaneously in two stages through an incision in the position of the lower fornix. This manœuvre illustrates the opportunism which must play such a part in a plastic surgeon's practice. Seldom are two wounds exactly similar. Use has been made of the spare conjunctiva from a socket doomed to be permanently hidden by a "patch," in one case to line a new cheek, and in another to line a portion of the nasal cavity; in either case the principle of restoration in kind is exemplified.

Facial Burns.—The facial burns met with are of two broad types, superficial and deep. Superficial burns are commonly found in gunners—cordite burns—in which case the ears are involved; and in airmen—petrol burns—in whom the damage is delimited by the margins of the flying helmet. Deep burns are rare. Those caused by Verey light projectiles form a class by themselves in which the damage by burning is superimposed upon that by the momentum of the missile. The subjects of these terrible injuries rarely survive the repair of them.

Cordite and petrol burns produce injuries which are remarkably constant in their extent, the subjects of them often presenting a strong facial resemblance to one another when the reaction to the injury is completed. The burnt area is covered with scar tissue which, on the cheeks and chin, is keloidal;

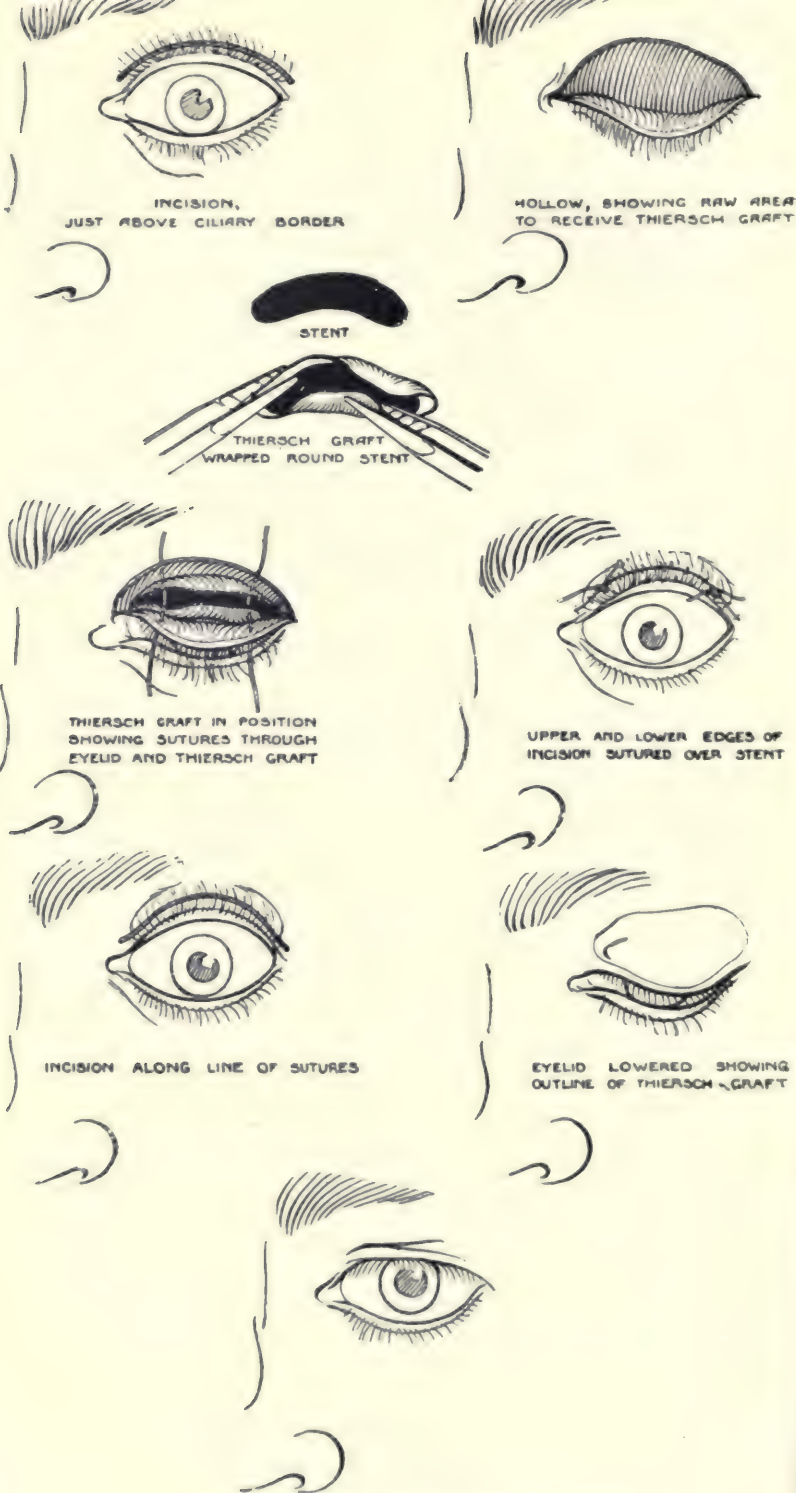


Fig. 54.—Stages in the epithelial outlay.

on the forehead, smooth, pink, and shiny ; and upon the nose and upon the ears, if these be involved, white. There is severe double ectropion of the lids, microstoma, and loss of the *alæ nasi* and eyebrows, and dense raised bands accentuate the naso-labial folds.

Relief of the ectropion is first indicated. The method employed is one evolved from the Esser inlay, and has been termed the epithelial outlay. Fig. 54 illustrates the details of the method. An incision is made skirting the lid edge, and the lid liberated by dissecting freely until closure can be effected without tension. In the resulting cavity is buried a closely fitting Stent mould covered with a Thiersch graft, over which the edges of the incision are sewn with horsehair, the sutures taking up the edges of the skin-graft. After some eight days the Stent either falls out or is removed and the lid falls easily into position.

The relief of microstoma presents no difficulty. The buccal orifice is widened at the angles and enough scar tissue excised to permit of the resulting raw area being covered by the suture of skin to mucosa over it. It is sometimes best to carry out this procedure in small stages.

The restoration of the large losses of skin upon the cheeks, chin and nose is carried out *en masse* from the chest, a procedure rendered possible only by the development of the tubed pedicle flap. The first stage consists of the preparation of one or more large tubed pedicles, their upper ends based upon the neck just below the collar line, and their lower ends continuous with areas upon the chest which are accurately mapped out to fit the scarred areas upon the face.

A fortnight or more later the keloidal scar is completely dissected from the face, and the chest flap swung up on its one or more pedicles and sewn snugly into the bed prepared for it. The epithelialized scar from the face may be sutured over the raw chest area which it fits accurately and where it forms a very suitable dressing. Much of this scar commonly "takes." If it fails, the area is either left to granulate or is Thiersch grafted. A month or more later, in the type case, the pedicles are severed at their junction with the face flap and spread out again over the areas of neck and chest which they previously occupied. (Figs. 55 to 57 illustrate these stages.)

More often, however, they are severed at their lower ends, and the skin composing them is utilized to cover some further portion of the face, or to aid in the reconstruction of the *alæ nasi*, and other structures.

The eyebrows are replaced by a "bucket-handled" tubed pedicle flap from the scalp, based upon the temporal regions and swung forward and downward; the pedicles are returned to the scalp when the eyebrow part has "taken." A strip of



Fig. 55.—To show tubing of pedicles and undercutting of flap.

hairy skin now runs unbroken from one external angular process to the other, and several small plastic operations are necessary to arrange for a hairless patch over the glabella and give a natural appearance to the hairy part. It is perhaps

better to make these eyebrows by two separate lateral flaps not joined in the middle. The patient is instructed to encourage the hairs to lie at the correct angle by the use of cosmetics and daily brushing.



Fig. 56.—Flap in suppurating stage.

Facial Prostheses.

Facial prostheses are sometimes called for where, for any reason, further plastic surgery is impossible, or as a temporary expedient. They may be divided into nasal, oculo-facial, aural prostheses and facial masks. In all cases an accurate plaster facial cast is necessary. The prostheses may be constructed by electro-deposition, casting in silver, vulcanite, or gelatine (Henning's process). In all except the gelatine method the prosthesis requires careful colouring, and its junction with the tissues should be concealed by the use of a little grease paint. The gelatine is self-coloured.

Metal replacements in the form of large facial masks, or for nasal and aural losses, have been failures owing to their weight. Electric deposition produced masks which fitted but broke frequently.

When constructed of vulcanite nasal prostheses are retained in position by a heavy pair of spectacles, or if there is a palatal perforation by attachment to the superior surface of the dental



Fig. 57.

plate. In the former case a piece of metal is vulcanized in the nose at the position of the bridge, and the spectacles riveted to this.

When the gelatine process is utilized the nose is first modelled in wax, and a die and counter-die made in plaster of Paris. The tinted gelatine is heated and run into this die. When set, it is removed and attached to the tissues by means of spirit-gum.

Such noses require frequent renewal, and the patient is given the mould and instructed in its use.

Oculo-facial prostheses are used in cases where there is loss of eye socket and contiguous tissue. A suitable eye is selected and attached to the facial cast ; the loss is then reconstructed in wax, wire inserted for eyelashes, the eye removed and the

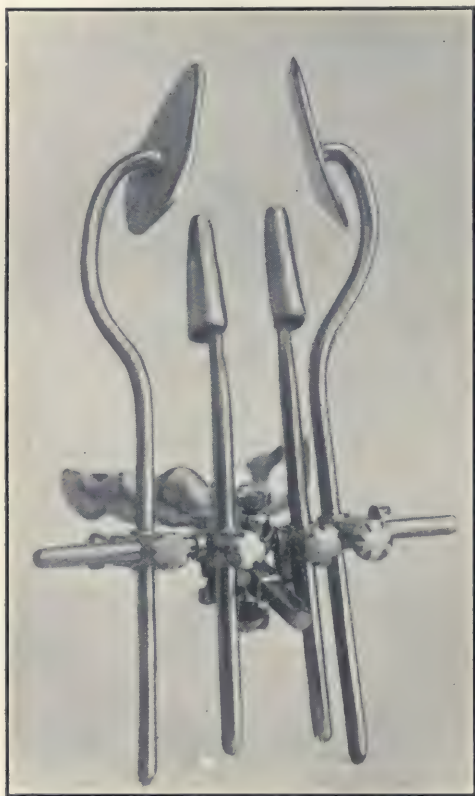


Fig. 58.

remainder cast in metal. The cast piece is replaced in position and a suitable pair of spectacles soldered to it. The artificial eye is fixed in position by burring up the metal. Oculo-facial prostheses can also be made by the gelatine process.

Aural prostheses are best constructed by Henning's gelatine process in a die and counter-die as already described.

Facial masks may be of vulcanite or gelatine and are retained by spectacles or dental attachments.

Splints for fractures of nasal bones and as supports for subsequent plastic work are employed. A fixed *point d'appui* is of great importance. Whenever feasible the teeth should be employed. Fig. 58 illustrates a universal splint. It consists of a cap splint for the teeth, a special one being required for each case, to which is soldered a square bar. The nasal appliance consists of a round, horizontal bar soldered at right angles to a tube fitting the square bar on the cap splint, and capable of being fixed at any point by a screw. There are four attachments working on this bar, two intra-nasally and two extra-nasally; these slide in vertical tubes soldered to horizontal tubes fitting the bar. Locking is obtained at any point by means of screws, so that any movement of any one of the attachments may be obtained.

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CHAPTER III.

WOUNDS OF THE NECK.

GUNSHOT wounds of the neck form a large and important group in military surgery ; and in order to obtain information regarding them the notes of 1,873 cases treated in home hospitals during 1914 and 1915 have been examined. Although many of these notes are of little value because of the absence of accurate details, yet they disclose the relative frequency of wounds of the parts affected. Thus injuries of the larynx occurred in the proportion of 1 in 17 of the neck wounds. Moure states that in the Crimean War the proportion was 1 in 460. Delorme gives the proportion in the war of 1914-18 as 1 in 33. Wounds of the trachea, on the other hand, were very rare—1 in 156. Injuries to the pharynx were the most difficult to estimate because they were generally associated with lesions of other parts, such as the face, jaws, larynx, œsophagus, chest, or spine. It was noted, however, that injuries to the jaws and pharynx were much more common than wounds of the larynx.

All varieties of wounds were met with, from simple punctures to highly lacerated forms, perforating wounds being far more common than penetrating. The entry wound might be situated in any part of the neck or jaw, rarely in the chest, and was generally smaller than the wound of exit. In the majority of cases the wound of entry was found in the anterior triangle of the neck. Transverse wounds were twice as common as oblique. Wounds in the middle line in front were very rare and never occurred posteriorly, doubtless because the spine was involved with fatal results. The track of the missile might be horizontal, from above downward, or occasionally from below upward.

In 108 cases of injuries to the larynx in which reliable notes were obtained the wounds were believed to be caused by bullets in 58, shrapnel in 20, shell fragments in 16, bayonet in 1, not stated in 13. The course was left to right in 26, right to left in 18, right only in 13, left only in 12, middle line in 5. The high proportion of bullet wounds suggests that these cause lighter injuries than ragged fragments of shell. In

the Bradshaw lecture on "Wounds in the War," Bowlby has shown that "the main injury of the parts is due to the divulsive nature of the missile, the tissues being torn asunder from within rather than from without."

In general, a bullet fired at short range is more destructive than after a long flight. In the former the missile is wobbling, whereas in the latter the course is steadier and the throat may be pierced so neatly that it is impossible to detect any injury. That bullets may pass through the neck in intimate relation to vital structures without causing serious damage must be emphasized. Many instances could be cited. Thus in two cases the bullets entered the neck in the middle line in front of the thyroid cartilage, and emerged posteriorly to the left of the dorsal vertebræ at the level of the spines of the scapulæ. As the notes stated, these bullets took an extraordinary course, and apparently no important injuries were sustained. In a third case a missile is stated to have passed through the trachea and œsophagus and lodged in the apex of the right lung, causing aphonia, dysphagia and emphysema, but the patient made an uninterrupted recovery. Again Moure says, "missiles passing transversely frequently dissect their way through the neck better than the most skilful surgeon." On the other hand, specimens in the Museum of the Royal College of Surgeons demonstrate that wounds seen on the battlefield are often much more severe than those which arrive in hospitals in civil life.

The healing of wounds of these regions is, generally speaking, rapid and satisfactory; a clean puncture through the pharynx, larynx, or trachea without injury to any vessel or nerve, may heal so completely in a few days that it may be impossible to detect any lesion in the throat. A small wound, if deep, may however be serious owing to hæmorrhage, shock, heart failure or sepsis. Large, ragged wounds are always dangerous because they so often become septic, the cellulitis leading to secondary hæmorrhage, gangrene, septicæmia and lung infections. Occasionally gas gangrene has been reported, and in one case tetanus developed. In the pharynx healing is often imperfect, and a fistula sometimes involving a salivary gland may result, in which case the wound closes slowly unless cured by a plastic operation. Wounds of the larynx are liable to be followed by œdema, and one must always be prepared for tracheotomy. Later on the inflammation may cause ulceration, perichondritis, necrosis of cartilage, and scarring. The fact that a considerable number of these cases afterwards develop

fibrous tissue like cheloid within the larynx raises the important question of the nature of the infection. A definite organism may be responsible for this form of inflammation.

Symptoms.

In many cases the classical symptoms are remarkable by their absence. Missiles can undoubtedly perforate the air-passages without causing either cough, dyspnœa, hæmoptysis or dysphagia. But as a rule the voice is lost immediately; cough supervenes and hæmoptysis is common and may be severe, some patients having stated that they had lost "at least two quarts of blood." Bleeding may be caused by injury to the carotid artery or to the internal jugular vein or may originate from the mucous membranes without injury to any large vessel. The hæmorrhage may continue for a few minutes or for long periods such as two to seven days. Recurrent and secondary hæmorrhages were rare in the base hospitals. Dysphagia is common but generally disappears after a day or two, and is due more to soreness than to inflammation. Even after severe wounds of the food passages there may be no dysphagia. A bullet which passed through the pharynx behind the larynx is said to have caused no dysphagia, dyspnœa or hæmoptysis. Dyspnœa occurred in 28 cases out of 110, and tracheotomy was required in 18. Even with severe wounds it was often absent and several of these patients were able to walk to a dressing station. A word of caution is necessary, however, for dyspnœa may develop unexpectedly even after apparently simple injuries and at almost any period. Richards reported a case in which the patient died of dyspnœa on the second day. Two other patients died of dyspnœa and heart failure before relief could be afforded. Two patients also required emergency tracheotomies in camp after returning to duty. Emphysema is mentioned rarely and gives rise to little trouble. Slight degrees are probably common and occasionally the whole neck and face are swollen.

Nature and Effects of the Injuries.

To estimate the damage sustained in injuries of the neck is often a difficult matter. As soon as the patient is well enough the examination should be methodical and include inspection, palpation and laryngoscopy, if necessary, by direct methods. An X-ray photograph should always be taken. Wounds in the upper part of the pharynx are generally

associated with fractures of the jaws and any important structures, such as the tongue, palate, cervical vessels and nerves, may be involved. Lower down, the epiglottis may be shot away, detached from its origin or perforated. The hyoid bone is often fractured and wounds of the thyroid cartilage are common. In cases that survive, the missile may have perforated the cartilage without causing any serious injury. Wounds of the arytenoids are more serious and fixation of the crico-arytenoid joints may result. When the cricoid is fractured or perforated serious complications are to be feared. In all wounds of the cartilages perichondritis supervenes to some extent and healing is thereby delayed. Every variety of fracture, in some of which the cartilages are broken into many fragments, is shown in 25 specimens in the Museum of the Royal College of Surgeons. In these cases the complications were numerous and included hæmorrhage, cellulitis, œdema, emphysema, and infections of the lungs and mediastinum.

Within the larynx the soft parts are frequently injured, especially anteriorly. Slight damage may be quickly repaired, but extensive wounds result in serious deformities with scarring and the formation of webs. The ventricular bands if wounded may become so swollen that the lumen of the larynx is reduced to a slit, a form of stenosis which is often persistent. Hæmatoma rarely causes obstruction, but large effusions have occasionally been observed. Œdema to some degree is generally present after a wound of the larynx and its dangers have already been emphasized. Granulomata may result from prolonged inflammations and may be situated on the vocal cords or around the tracheotomy tube. Abscesses may form externally or within the larynx, especially when a foreign body is retained. If the abscess bursts internally the foreign body may be coughed up and the inflammation may rapidly subside. Peri-tracheal and peri-œsophageal abscesses are not uncommon and may necessitate tracheotomy. Fistulæ of the larynx may follow wounds or abscesses but in most cases heal rapidly. Wylie reported an instance of a persistent fistula which was explored and found to contain a piece of a coat collar, which being soft had not been detected. As usual, the fistula closed after its removal.

The frequency of paralysis of the vocal cords after gunshot wounds of the neck which did not involve the larynx is very remarkable. In 108 cases examined in England, left abductor paralysis was noted in 22 cases, the right vocal cord being affected in 14 and both cords in 2,

giving a total of 38 cases. The paralysis appeared to supervene immediately after the wound, and in the early stages was of the abductor type. In a few instances it disappeared after a time, but more often it was persistent or was followed by total paralysis. It has not been possible to determine the exact frequency of these changes because of the confusion which exists between fixation due to nerve involvement and to ankylosis of the crico-arytenoid joint. In most cases of paralysis the arytenoid is drawn forward on the affected side, a condition which has not been seen with simple fixation.

Paralysis may be caused by division of the recurrent laryngeal nerve, by its involvement in scar-tissue, by shock or perhaps by toxæmia. Vagus paralysis and central lesions are very rare. It is important to determine which of the above is responsible. No instance of the finding of a divided nerve has been reported, and the paralysis seems to supervene too early for scar-tissue or toxæmia to be responsible. There can be little doubt that contusion and the radiating effects of missiles are generally responsible, for several reasons, of which mention may be made of the following. Considering the deep position of the laryngeal nerves, it is inconceivable that they could be injured in the large number of cases which were reported. In many instances the course of the missile was far removed from the nerve that was paralysed. Körner, for example, quotes a case of a subcutaneous glancing wound of the right side of the thyroid cartilage which without penetrating the larynx caused a lasting fixation of the right vocal cord.

Paralysis of the other cervical nerves, excluding the brachial plexus, was comparatively rare. Thus in the cases observed by Douglas Harmer the internal laryngeal nerve was injured only twice, the external, the vagus, spinal accessory, sympathetic and hypoglossal nerves once each.*

Two cases of paralysis of the left recurrent nerve, caused by a bullet and a fragment of a shell respectively entering through the chest wall and becoming impacted in the arch of the aorta, are reported by Abercrombie and Mollison.

Two cases are reported in which a missile caused double abductor paralysis. Moure quotes another instance of this lesion of uncertain origin.

Paralysis of the brachial plexus is frequently caused by

* Moure has seen eight cases of paralysis of the vago-spinal. Mollison had a case of injury to ninth, eleventh and twelfth nerves. In wounds high in the neck the tenth, eleventh and twelfth nerves are occasionally involved.

wounds of the neck, and generally all the trunks are involved and not one branch, as would occur if a direct injury were responsible.

Paralysis of the recurrent nerve has resulted several times from operations for ligature of carotid aneurysms, and is common after many other operations on the neck.

In other parts of the body operations are frequently undertaken to release nerves from scars, but in only one patient does this seem to have been attempted in the neck. Körner exposed the right facial, vagus, spinal accessory and hypoglossal nerves, and found them involved in scar tissue but not divided. Six weeks later improvement was noted in the spinal-accessory and vagus, but the palate and larynx were not improved.

It would seem that damage to various cervical nerves was dependent more on the degree of their fixation than upon their position in the neck. The fact that the recurrent nerves wind round the arch of the aorta and the subclavian artery respectively may prevent them from being easily displaced at the moment when the larynx has been strongly deflected by the blow.

After gunshot wounds of the larynx there is generally some obstruction of its lumen in the early stages which may be caused by general inflammation of the mucosa, by oedema, by abscess or by hæmatoma. The ventricular bands may be so swollen that they meet in the middle line and occlude the vocal cords. This condition is very persistent when perichondritis has supervened or when crico-tracheotomy has been performed.

Cicatricial stenosis may occur at the level of the vocal cords. A common form is webbing between the anterior ends of the true cords. The scar-tissue is remarkably tough and generally extends some distance down into the subglottic space. Such webs are very difficult to cure but are not so serious as the annular and tubular varieties, in some of which the lumen of the larynx may be almost obliterated. Strictures are also met with in the subglottic space and in the trachea. Paralytic strictures are rare.

Brown Kelly reported an interesting wound resulting in dilated glottis. "The bullet entered the larynx above the anterior half of the left vocal cord and escaped at the anterior commissure, causing damage chiefly in these situations. The right ventricular band was swollen until an abscess was opened. Later the swelling subsided, and when the patient was seen six weeks afterwards the anterior angle of the glottis formed a right

angle, so that on phonation a large gap remained posteriorly. The right vocal cord and arytenoid moved well but the left cord was motionless." A slight degree of bowing of the vocal cords is common after these injuries. Seymour Jones reported a case in which a fragment of shell traversed the cricothyroid space and caused paralysis of the cricothyroid muscles probably by injuring the external laryngeal nerves. A rough voice resulted on account of the difficulty of bringing the vocal cords into a state of tension.

With regard to injuries to the œsophagus, the cervical portion is sometimes perforated by missiles entering the neck near the larynx. In most instances dysphagia is of short duration and the absence of complications is remarkable. Cellulitis of the neck, peri-œsophageal abscess and fistulæ may supervene but are rarely fatal. Temporary dilatation for purposes of feeding has been necessary in several cases, but only one instance of a permanent stricture of the gullet has been discovered. It is possible that injuries of this character are more common than appears from the number that survive and come into the surgeon's hands.

With regard to injury to the trachea, foreign bodies may traverse the trachea without causing serious damage, though in most instances a fistula supervenes for a time. Severe wounds are likely to be fatal unless early treatment can be afforded. Moure reported a case in which a fragment of a hand grenade entered the neck and divided the right internal carotid artery, injured the vagus, the spinal-accessory and hypoglossal nerves, finally becoming impacted in the right bronchus, from which it was successfully removed seven weeks later with the aid of bronchoscopy. The patient recovered.

The large vessels of the neck lie entirely behind the larynx and are so deeply situated that they often escape being wounded. In the twenty-five post-mortem specimens in the Museum of the Royal College of Surgeons eleven patients had injuries to important vessels, and it is fair to assume that many such cases end fatally. Those that survive are the cases of slight injury causing aneurysms of the vessels of the neck.

After wounds of the air and food passages complications are always to be feared, especially in the early stages. Even simple wounds may terminate fatally. The danger of infections of the lungs must be emphasized. Bronchitis and pneumonia are mentioned in the records of nine of the twenty-five Museum cases.

Treatment.

The treatment of wounds of the larynx and pharynx calls for great ingenuity and experience. A primitive instinct creates anxiety about an injury in the region of the throat, and with gunshot wounds this anxiety is marked: It is important to keep this in mind, and to avoid all examinations and treatments excepting those which are absolutely necessary, but it is essential to watch the patient carefully to prevent him from choking. The notes of larynx wounds show that nearly one-third of the cases required a tube for breathing at some period of their treatment. The choice of operation depends upon the position of the wound and upon the condition of the patient. In general a local anæsthetic, such as infiltration with novocain, 2 per cent., is advisable, but in very nervous cases an injection of morphia and a general anæsthetic such as gas and oxygen may be better. For urgent dyspnœa a rapid laryngotomy is the easiest form of relief, and the wound can sometimes be utilized for introduction of a tube. Such treatment is only temporary, and after a few days must be followed by tracheotomy. Crico-tracheotomy is inadvisable because the larynx is narrower than the trachea and the tube is not well tolerated for many days. Swelling of the mucosa results from it, and later necrosis of the cricoid and granulations may supervene, leading to "retained tube," a complication which is much more common than after lower operations. "High" tracheotomy through the upper two or three rings is easier to perform and less dangerous than the "low" operation. The latter should be reserved for those cases where, after careful consideration, it is decided that a permanent tube must be worn.

The treatment of hæmorrhage is equally important. For primary bleeding the wound should always be freely exposed, so that the injured vessels can be found and ligatured if possible. Failing this, the external carotid may have to be tied. Plugging should be reserved for those cases alone in which the bleeding is venous or so general that no definite vessel can be found. Secondary hæmorrhage is undoubtedly common after wounds of the neck, and Whale states that it occurs mostly four and a half days after the wound, which is earlier than in other parts of the body. To treat this successfully it is necessary to open up the neck very freely so as to drain the infected area, and often to ligature one of the larger vessels.

The treatment of the neck injury should be directed towards the prevention of sepsis. Excision of lacerated tissues is important, and it is usually necessary to drain the wounds. Wherever possible the divided membranes and muscles should be sutured and the air and food passages restored, but there is evidence to show that the parts are liable to become gangrenous, and that fatal results are not uncommon. Foreign bodies should be removed whenever possible after careful localization by radiography. Failure to extract a foreign body renders the patient liable to hæmorrhage, sepsis, ulceration and other complications.

Careful feeding of the patient is important to recovery, and in many instances it is necessary to introduce a tube into the œsophagus for this purpose, and sometimes to leave it *in situ* for several days. The questions of warmth, moisture, inhalations, management of the tracheotomy tube, and careful nursing must not be forgotten.

The later treatment of complications can only be carried out by laryngologists. Wounds of the larynx are frequently followed by stenosis. As Moure says, "nearly all cases have perichondritis at first, some destruction of cartilage, others lesions of the arytenoid joints (serious complications), others injuries to the pharynx or œsophagus." It is important to remember that inflammatory stenosis may disappear entirely. Thus in several patients the early notes made by well-known laryngologists stated that permanent tracheotomy tubes would be necessary unless laryngostomies were performed; yet a year later these patients were breathing normally without tubes.

To lay down any general treatment of stenosis is impossible, but a method is required which will not only dilate the stricture but, if possible, will also cause absorption of the scar-tissue. Simple dilatation is only practicable in a few cases, and a removal of the scar-tissue is useless unless intubation is employed afterwards for many months. Moure, like other continental surgeons, is strongly in favour of laryngostomy, and his method consists in splitting the larynx and trachea and resecting all scar-tissue until the lumen of the trachea is opened up and canalized. The normal structures are often unrecognizable, but care must be taken to avoid both injury to the œsophagus and the removal of the ventricular bands. In one case the patient filled a large bowl with blood, and as there is always a danger of hæmorrhage Moure recommends cauterization of the bleeding points. After operation the

larynx is plugged by a roll of gauze containing an antiseptic, and this is changed every three or four days and replaced after three or four weeks by a vulcanite tube and cannula or by an intubation tube fixed by a clip. Granulations are treated by chloride of zinc, 10 per cent., or by silver nitrate. In some cases an œsophageal tube is used for feeding for a few days. Intubation is maintained for twelve to eighteen months, after which the cannula can generally be removed. To close the fistula a plastic operation similar to that used for epispadias is performed. A second laryngostomy is sometimes necessary. Moure points out that war injuries are far more difficult to handle than ordinary civil cases of stenosis, and that fixation of the arytenoid joints increases the trouble. The complications that he has experienced are inflammation, œdema, abscess, and necrosis of the cartilages of the trachea. The voice results are surprisingly good and, although rough, phonation is strong and resonant, similar to that obtained after removal of cancers by thyrotomy. Moreover, the patients are cured and can breathe through the natural passages. He has published the notes of sixteen soldiers and fifteen civilians treated with complete success. In his hands laryngo-tracheotomy gives excellent results, but it is an operation not to be undertaken lightly by other laryngologists.

In every case of "retained tube" the question of curing the stenosis should be carefully considered, and in many cases this can be effected by simpler methods than laryngostomy. A long period must be allowed to elapse after injury so that sepsis can subside, and care should be taken that the tracheotomy tube is placed well away from the larynx. In cases where crico-tracheotomy has been performed the tube must be reinserted in the "low" position, and then no further treatment is advisable for a period of from three to six months. In some instances this low tracheotomy is sufficient to cure the case, for as the inflammation subsides the lumen of the larynx is restored. In others, especially those with severe infections, scar-tissue is formed and must be treated either by dilatation or by some form of intubation, and an upward-turning stenosis cannula can often be inserted above the tracheotomy tube. A small-sized cannula should be employed in the first instance, and it should not be changed too frequently. After a month a much larger size can nearly always be inserted without difficulty. If patience is observed these tubes cause little reaction or pain to the patient, and the lumen of the larynx is gradually restored in from one to three years.

The cannula should be hollow, and there should be a window in the tracheotomy tube so that the patient can use his voice. The constant use of the voice helps to improve its quality. When possible the tracheotomy tube should be corked for varying periods so that the breathing is then entirely through the normal passages. Eventually the cannula should be removed, and the wound will then contract but should not be closed completely for six months. During this time the patient should be watched to make sure that he does not suffer from breathlessness, air-hunger and its consequences. If normal breathing has been restored the tracheotomy fistula may be closed by plastic operation.

Mortality.

The mortality of wounds in the pharynx and larynx is undoubtedly high, and depends upon various factors. In the firing line wounds which are extensive are rapidly fatal, and examination of statistics shows that patients rarely survive an injury in the middle line, doubtless because the spine is involved. Oblique wounds are also very dangerous, because the large vessels and nerves are often implicated. Of the survivors a large proportion are those who have received transverse wounds of the neck. At the base hospitals in France many deaths occurred in the first week after the injuries. Thus in 512 cases of neck wounds there were 31 deaths. On the other hand 1,873 similar cases were treated in hospitals in the United Kingdom during the same period with only 17 deaths. The above figures are important in proving that the mortality is much greater in the early stages of the wound. In those that survive for more than a week it was found to be less than 5 per cent.

In 47 cases of neck wounds the causes of death were given as follows:—Fracture of spine and paralysis 16, hæmorrhage 7, aneurysm 2, broncho-pneumonia and gangrene 2 each, pneumothorax, dyspnœa and heart failure, septicæmia, mediastinitis 1 each, no cause stated in 14; but general sepsis and septic infection of the lungs were more common than is indicated by these figures and certainly caused many deaths. In 32 cases of fatal wounds of the larynx the deaths were due to sepsis of the neck, mediastinitis and broncho-pneumonia in 9, hæmorrhage in 5, pneumonia in 3, meningitis in 2, mediastinitis, hæmothorax, pericarditis, œdema of larynx, tracheotomy and heart failure, cellulitis of the neck, septicæmia and cerebral embolus in 1 case each. In 5 the cause was not stated.

In 17 of the above cases death occurred within seven days, 6 being within twenty-four hours. The commonest causes of death in the early stages were hæmorrhage and dyspnœa. Later on inflammation of the neck extending to the chest and involving the lungs was mostly responsible. To prevent broncho-pneumonia Richards suggests that in all grave wounds laryngostomy should be performed and the air passages plugged above the tube.

After Results.

In two-thirds of the gunshot injuries of the larynx where the patients survived for more than a week recovery was complete and no ill effects were left beyond alteration of the voice. The voice results noted in 70 cases were normal 17, "strong-hoarse" 24, "weak-hoarse" 12, "falsetto" 1, "whisper" 15, "dumb" 1. Examination of many of these cases has shown that faulty voice production is often responsible for the loss of voice. Officers, as a rule, obtain a useful voice more quickly than men, but the result is variable even in the same type of injury. In 10 cases of webbing of the anterior commissure, the voice was strong-hoarse in 3, weak-hoarse in 3, falsetto in 1, whisper in 2, and dumb in 1. It appears, therefore, that serious voice defects are much rarer after gunshot wounds than as a result of neuroses without injuries. Thus Smurthwaite reported 262 cases of the latter which he had treated, including 239 sufferers from aphonia, 13 mutes and 10 stammerers. In these patients the laryngeal changes noted showed four variations, namely, vocal cords elliptical owing to paresis of thyro-arytenoideus internus muscles; cords abducted owing to paresis of adductor muscles; cords and ventricular bands drawn tightly together; and cords adducted anteriorly only owing to paresis of arytenoideus muscles.

As regards paralysis, there is evidence which shows that this rarely recovers. Moure quotes a case in which an abductor paralysis disappeared after the evacuation of a peri-œsophageal abscess through the pharynx. Körner also has seen a recovery of abductor paralysis. On the other hand, in a small number of patients total paralysis supervenes. The general health of these patients is good as a rule. A small proportion of the cases suffers from mental depression. They complain of breathlessness on exertion, inability to lie down at night or to undertake work in any form. Neurasthenia is not common, but in one instance the patient committed suicide after he had recovered.

In conclusion, it may be stated that very many lives are undoubtedly lost from gunshot wounds of the neck, pharynx and larynx. It is important, therefore, to improve the methods of treatment and it is also desirable if possible to prevent the occurrence of these wounds by protecting the neck. Experiments have been carried out which show that necklets of Japanese silk are proof against shrapnel splinters possessing a velocity of 650 foot seconds. One hundred of these necklets were tried in France by the First Army and reported useful for bombers in advanced positions where little movement is entailed, but not of use in action as movement would be too much restricted. Two hundred were recommended for each division. The Second Army reported that they served as a protection against small splinters of shrapnel and recommended 500 per division.

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CHAPTER IV.

INJURIES TO THE SPINE AND SPINAL CORD.

IT is difficult, if not impossible, to form any opinion as to the number of cases of injury to the vertebræ and their contents which were met with during the war, as very many of these would fall into the category of killed or missing, but it is certain that the number was very large. Wounds by missiles were also in many cases associated with most severe injuries of the thoracic or abdominal organs, and such cases rarely permitted of detailed surgical investigation. It follows that such conclusions as can here be drawn are mainly derived from a consideration of the less severe and more localized injuries and especially from those in which the wound was received from the back or side, but not through the great cavities of the body.

Injuries of the Vertebræ.

In civil life fractures or "fracture-dislocations" of the spine are by far most commonly due to over-flexion of the whole vertebral column. The type of injury is very uniform, the upper vertebræ being displaced forwards with more or less crushing of one or both of their adjacent bodies on their anterior aspect; the laminae and processes are often broken off by traction on their intervening ligaments, and the spinal cord is crushed and reduced to a diffuent blood-stained pulp, which may extend vertically for half an inch or more. The displaced parts then either remain in their abnormal position or they "recoil," in which latter case the lumen of the spinal cord is largely or entirely restored, but the crushed cord remains as a permanently injured structure with no power of repair. Throughout the war injuries of this well-known type were not infrequent as the result of falls, and especially of burying in trenches, dugouts and the like, but they presented no variation from the familiar "fractured spine" of civil life.

Gunshot wounds, on the other hand, present a far wider pathological variation. Apart from the new elements introduced by sepsis and by the pressure of foreign bodies, the bony injury is more likely to involve only the outlying processes of the vertebræ and, except in the very fatal cases of anterior wounds, the part played by displacement of the

vertebral bodies is much less conspicuous. Angular curvature, whether permanent or temporary, is not characteristic; widespread and irregular fractures of laminae, spines, and transverse or articular processes are common; the cord is not, as a rule, crushed by kyphosis but by indriven fragments of bone or metal, or it may be compressed by hæmorrhages and later by cicatrices; and it is also subject to grave damage from the divulsive wave of a missile moving at high velocity, a factor totally absent in civil injuries.

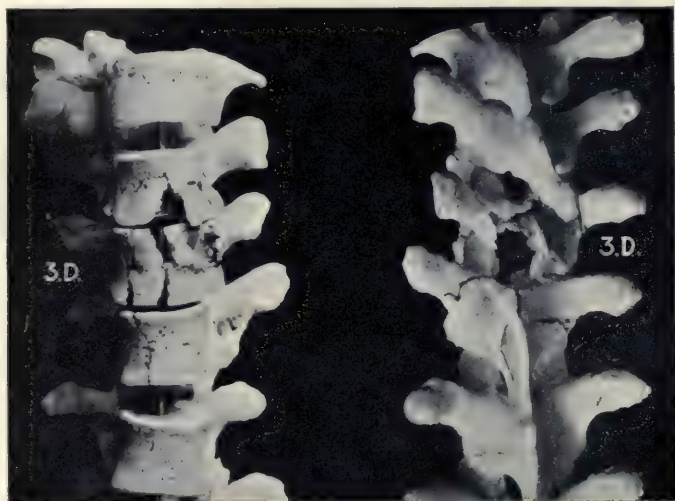


Fig. 1 shows the entry wound at the bodies of the 2nd and 3rd dorsal vertebrae.

Fig. 1A shows the exit wound involving chiefly the 3rd dorsal vertebra.

Fractures present two types, namely (1) abrasions, crushings and perforations due to direct impact and often associated with complete pulverization of the bones, and (2) cracks and fissures of the vertebral processes which may be due either to direct impact or to traction upon their ligaments. In the case of such cracks and fissures there is often evidence of recoil, the displaced fragment having fallen back more or less accurately into its original position, although before so doing it may have most seriously injured the subjacent cord. In very many cases the bony arch is broken at two points, which are often more or less diagonally opposite to one another, a segment of the irregular circle of the neural arch having thus been detached.

These various forms of injury are well illustrated by the War Office collection of dried specimens, and the following figures taken from the *British Journal of Surgery* for April 1919 will serve to show some of the types. Fig. 1 shows the line of passage of a rifle bullet through the second and third dorsal vertebræ; the entry wound from the left front presents extensive crushing and pulverization; the exit wound shows direct crushing of the third dorsal lamina, with well-marked cracks in the adjacent processes, but no displacement. In Fig. 2 a missile, of which the nature is unknown, passed through the right lung and liver, impinging upon the body of the eleventh dorsal vertebra; here it passed through the front of



Fig. 2.—Fracture of body of 11th dorsal vertebra, and fracture of 12th dorsal at "seat of election."

the right lamina, blowing out two more or less triangular fragments of bone, and then pulverising the left lamina (not shown in figure); subsidiary fissures involve the spinous process of the eleventh dorsal vertebra, the superior articular process of the twelfth dorsal vertebra and the junction of the right twelfth lamina with its body. The latter point, at which the denser bone of the lamina joins the cancellous tissue of the body, is so common a site of fracture that it may almost be regarded as a "seat of election" of fractures due to gunshot wounds.

A good example of extensive fissuring is also shown in Fig. 3. The patient presented a wound over the left shoulder, with a metal fragment lying opposite the middle of the left sternomastoid muscle. From the transverse process of the sixth cervical vertebra a small fragment of bone has been blown away, opening the foramen for the vertebral artery. The fifth cervical vertebra shows several clean fissures, involving the bulk of its lateral mass. Of the fourth vertebra the lower articular process is blown away; of the third the left lateral mass is completely detached by clean fissures but



Fig. 3.—Injury to 3rd, 4th, 5th and 6th cervical vertebræ. The injury to the spinous process of the 7th is an artifact.

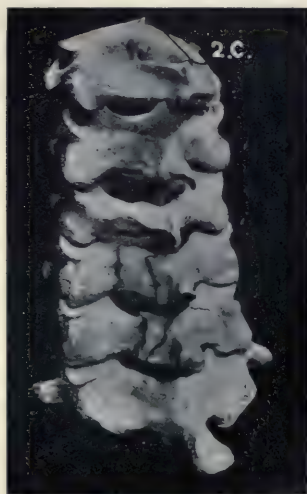


Fig. 4.—Cervical spine. Fracture of 5th and 6th arches.

is not displaced; there was also a clean fissure through the right lamina of this vertebra. With all these extensive injuries there was no penetration of the spinal canal, and the cord was not compressed but presented a fatal hæmatomyelia.

An example of the slight bony lesion which may be associated with the most severe results is shown in Fig. 4. The patient was admitted to hospital with gas gangrene of the right thigh and buttock, and died within an hour, without any spinal injury being suspected. At the autopsy the distension of intestines and bladder without any sign of local inflammation

led to a careful examination of the spine, where there was found a minute through-and-through wound of the neck. On laying this open a double fracture of the fifth and sixth cervical arches, with no displacement, was revealed, although the fragments were quite separable after maceration; there was a little blood-clot around the untorn theca, and the spinal cord presented a central hæmorrhage. There can here be little doubt that the small detached fragments of bone had crushed the cord and recoiled.

In the above cases, as in the majority of the post-mortem examinations which have been made, no foreign body is retained in or near the spine itself, but in others such fragments remain. A favourite seat for impaction is the interior of the spinal canal or the posterior part of the vertebral body; and smooth round objects, such as shrapnel bullets, may slip

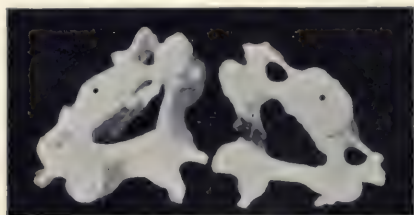


Fig. 5.—The 4th and 5th cervical vertebræ. The 5th (right) shows fragment of metal *in situ*; the 4th (left) the depressed spicule of bone.

downwards, especially if they lie within the theca. Fig. 5 illustrates a minute fragment of metal impacted in the fifth cervical lamina, where it has produced a perforation large enough to admit a lead pencil, and whence it has driven a small fragment of bone (shown in the left-hand figure), which had pierced the theca and partially divided the cord. Fig. 6 is a typical example of lodgment of a metal fragment in the posterior part of the vertebral body.

The above cases illustrate some of the more common types of the very various forms of injury. For the purposes of description such injuries may be classified as follows :—

I. Fractures by direct impact—

- (1) With complete perforation by the missile.
- (2) With retention of the missile.
 - (a) In the bone.
 - (b) In the spinal canal.

II. Fractures by tangential injury—

- (1) The missile coursing along the spine.
- (2) The missile coursing across the spine.

In the latter class fractures are probably sometimes due not to any direct impact upon the bones but to traction upon the soft parts, and recoil is common so that the bony injury actually seen is no guide to the gravity of the temporary displacement. In few cases is the extent of the bony injury any measure of the damage inflicted upon the contents of the vertebral canal.

It will be clear from a consideration of the pathological conditions met with that the radiographic examination of spinal injuries presents peculiar difficulties, apart from those of obtaining good pictures of this region. The bony changes shown in the shadow are often highly complicated, nor is

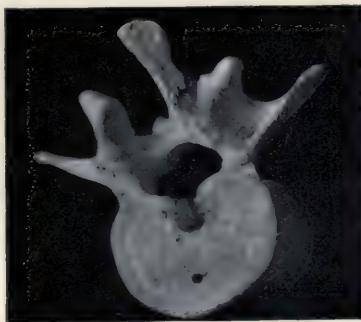


Fig. 6.—Metal embedded in the body of 2nd lumbar vertebra. Incomplete fracture at base of spinous process.

bony displacement accurately indicative of the temporary displacement which may have occurred. It is, however, important in all cases to obtain skiagrams if possible, and much may often be learnt from the presence of bright spots in the negative, due to fragments of metal left by the bullet in its course, which may show the line taken by the missile even better than does the actual fracture.

Injuries of the Meninges.

In very many cases, and especially in those of tangential injury of the bones, the dura mater is untorn, and as its outer surface is highly resistant to infection it is then quite usual to find either no affection of the meninges or the merest

staining from bruises. Cuts, tears, scratches, and perforations occur, however, as the result either of direct impact or transfixion by the missile, or of a less direct impact from fragments of bone driven inwards by the missile. In such cases the seat of the thecal aperture may or may not be infected, and for obvious reasons it is more liable to be infected by a missile, especially by a missile accompanied by fragments of clothing, than by pieces of bone, which are far less prone to be themselves septic. The War Office collection in the Museum



Fig. 7.—Impaction of fragments of bone in spinal cord; no septic infection,

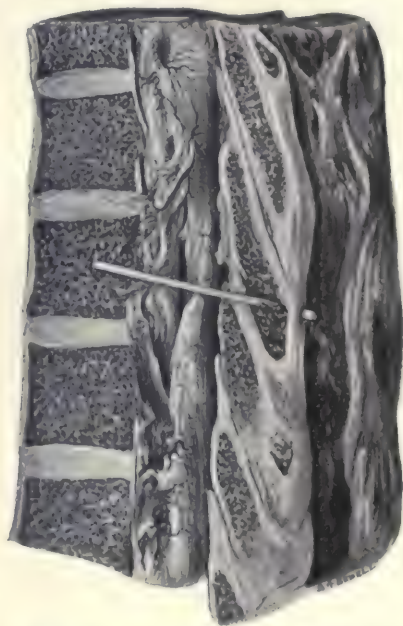


Fig. 8.—Tangential wound of spinal cord.

of the Royal College of Surgeons contains many specimens, presenting many variations of the results thus produced, and a number of them have been illustrated and described in the *British Journal of Surgery* for October 1920.

Figs. 7 and 8 illustrate uninfected tears of the theca spinalis, the first being an example of perforation by a minute fragment of metal; the second, a tangential wound by a rifle bullet. In Fig. 9 the reaction is of the slightest, but there is some residual hæmorrhage, which is almost invariably met with, and which tends later to be productive of a cicatrix. In the



(a) Contusion of cord :
no injury to theca.



(b) Fragment of metal
impacted in cord ;
tear in theca, localised
meningitis.

specimen from which Plate I (*a*) is taken there is extensive hæmorrhage from contusion of the theca, but this was untorn, and there is no spreading or infective meningitis. Slight but clean tears commonly present light adhesions to the subjacent spinal arachnoid or again to the cord, and it is quite common at operations to observe a gush of cerebro-spinal fluid on separating such adhesions. In a good many cases such fluid may be enclosed by adhesions and give rise to the so-called "cysts," which have been constantly described as met with at operations.

Alternatively, the substance which has wounded the theca may also have infected its interior, and then there is a more or less widely diffused meningitis. In these cases there is beneath



Fig. 9.—Perforation of spinal cord; no septic changes.
Result after one month.

the arachnoid a yellow or grey deposit of pus, which spreads out between it and the spinal cord. Such a deposit may extend throughout the entire spinal canal. In other cases it may have spread in one direction only—generally upwards—its extension having apparently been limited on one side by the formation of adhesions. Again, the leptomeningitis may extend to the brain, where it may be of a more intense degree. In two cases observed, although the inflammation appeared to die away in the cervical region, "in the brain there was extensive purulent meningitis, with pus in the ventricles and a small hæmorrhage in the floor of the fourth ventricle." Still more striking is a case of leptomeningitis from

a wound in the lumbar region, in which the vertex of the brain showed a most extensive exudation, although there was no trace of such at the base.

Free intrathecal hæmorrhage sufficient to gravitate to the lower part of the canal and by accumulating there to cause an ascending paralysis has occasionally been met with, but is rare. Although blood-clot is often extensive around the theca, it is but seldom met with as a source of pressure within that membrane.

Two other points are worthy of note in connection with injuries of the theca spinalis, as they may be of diagnostic importance. In clean cuts and stabs the escape of cerebro-spinal fluid through the wound may be profuse and may even be the only indication of a meningeal injury; in gunshot wounds this condition was not met with in the cases observed, possibly on account of the general swelling or of adhesions closing the aperture. Lastly, foreign bodies, especially those which are round and smooth, may after penetrating the theca slip down within its cavity even to a distance of an inch or more; and this has been actually known to occur upon the operating table.

Injuries of the Spinal Cord.

The spinal cord may be directly cut by a missile or a fragment of bone which either transfixes it or remains imbedded in its substance. Such injuries are very common and are illustrated in Fig. 7 and Plate I (*b*). Again, it may be contused without section, as in the case shown in Fig. 10, in which a shrapnel bullet lying outside the dura has irreparably bruised the medulla. In another case, a bullet, entering base first between two laminæ, slightly indented and tore the dura, again producing a fatal bruise. Less obviously a missile passing tangentially to the spine may by its "divulsive" action contuse the cord without even entering the vertebral canal. In one remarkable case a bullet passed through the base of the seventh cervical spinous process without entering the vertebral canal, but by its divulsive force caused a hyper-extension of the neck (an exaggeration of the normal curve) so that three or four of the vertebral bodies were slightly separated and the enclosed cord and meninges bruised and crushed. Here we have the antithesis of the injury to the cord caused by ordinary "fracture-dislocation"; in the latter the canal is narrowed by over-flexion; in the case in question it is narrowed by over-extension. Again,





(a) Slight bruising of theca ; extensive injury to cord.



(b) Extensive hæmorrhage from slight bruising (or concussion) of cord.

cases are recorded by Claude and Lhermitte, and by Collier in which the bursting of high explosives, especially behind the soldier, has caused all the appearances of a contusion of the cord, without any external wound at all.

Whatever the injury, the results so far as the cord is concerned are, however, closely similar. The softness of its structure renders it peculiarly sensitive to any contusion or blow, however



Fig. 10.—Lodging shrapnel bullet with contusion of cord.

slight. There results a hæmorrhage associated with grave destruction of nerve cells and fibres and, in accordance with previous experience, incapable of repair. The resulting condition is shown in many of the figures to which reference has already been made, Plate I (*a*) being a good example of contusion without any injury of the theca. The extent of such bruising is well shown in Plate II (*a*), while Plate II (*b*) illustrates in a series of sections taken over a distance of 3 in. the

tendency of the hæmorrhage to involve the softer grey matter. The minute changes met with in these cases have been very fully described, but do not differ materially from those previously recognized as resulting from the crushing injuries of civil life; they are solely necrotic and degenerative and there is never any evidence of repair of nervous tissue.

In addition to the above more or less direct injuries of the spinal cord, Collier and others describe "remote lesions" which may be found at a considerable distance from the point struck, and consist of areas of hæmorrhage, necrosis or œdema attributed to a general rise of intrathecal pressure. That there is a widely spreading wave of cerebro-spinal fluid throughout the spinal area and probably extending to the cranium can hardly be doubted, and to the effects of such a wave some of the early symptoms are probably attributable. It is by no means improbable that small remote lesions resulting from such a wave may evoke the well-defined symptoms of contusion of the cord after falls and blows, or the bursting of shells in which there is no actual wound, and Claude and Lhermitte describe several interesting cases of this type, which they attribute to a "pure necrosis without thrombosis or hæmorrhage."

Symptoms.

In the great majority of cases of gunshot injury to the spinal cord the early symptoms conform to the type of complete interruption of functional continuity, and the earliest stage usually observed is that of "spinal shock" in which all function is abolished below the lesion with complete anæsthesia and flaccid paralysis. This may, however, be associated with symptoms closely resembling those of cerebral concussion, such as unconsciousness and subsequent vomiting and headache. These transient cerebral symptoms are stated to be more common in wounds of the cervical region and are regarded by Collier as evidence that a missile has traversed the spinal canal; they probably arise from the upward impact on the medulla oblongata of a wave of displaced cerebro-spinal fluid, producing results similar to those of the downwards wave of cerebral concussion; they seldom, if ever, last for more than a brief period, and they are no longer likely to be recognisable when the patient reaches hospital. Possibly they may be a cause of death before any help can be rendered.

The typical condition after injury will, however, be at first one of flaccid paraplegia, and at this stage it is seldom, if ever,

possible to form an opinion as to the extent of anatomical injury. The syndrome is identical whether the cord be cut across by a missile or a bony fragment, bruised by a temporary impact, as from bony displacement with recoil, or merely concussed from the divulsive wave of a passing bullet.

In the course of a few days or even of a few hours changes will ensue, and it may then become practicable to form an opinion as to the amount of injury sustained. On the one hand shock passes away and the uninjured nerve cells and fibres may recover their activity; paralysis and anæsthesia become more limited and defined and the stage of "anatomical definition" is reached in which it is possible more accurately to recognize the segmental level of injury, or even to locate that injury to one side of the cord, as in the Brown-Séquard syndrome which is by no means rare. On the other hand softening tends to spread and usually marks its presence by a steady upward extension of symptoms for one or two segments. Less commonly the increasing pressure of hæmorrhage may also be a cause of progressive symptoms.

In connection with this stage there has been a careful study of the reflex functions of the cord below the lesion, especially by Collier, Head and Riddoch, which has considerably modified previous teaching. Until about 1890 the classical experiments of Goltz were taken as showing that a complete transverse lesion of the cord was followed by retention or even exaggeration of reflex activity below its level. The work of Bastian and others showed, however, that in complete paralysis and anæsthesia (generally from "pressure" lesions of slow onset) the "deep" reflexes were lost and the view was accepted that the presence or reappearance of such reflexes after injury was evidence of an incomplete lesion or of some regeneration. This view was very widely, though not invariably, accepted and was to a large extent confirmed by the earlier observations. Collier laid down the following criteria for prognosis. Early reappearance of a plantar reflex, if at first lost, or a change from the flexor to the extensor type soon after the seventh day or the presence of an extensor response earlier than this are certain indications that the lesion is partial and that some recovery will occur. Persistent loss of plantar reflex and long standing flexor response are indications that the lesion is severe. Early return of knee- and ankle-jerk is of good prognosis; if it occurs before the fourth day complete recovery will probably ensue. Return of sphincteric control is of very good prognosis.

Riddoch, examining cases at a date more remote from the injury, found, however, that "a clinical study of several examples of complete division of the spinal cord due to wounds of war has shown that the clinical picture hitherto described as typical is imperfect. Under favourable conditions that portion of the spinal cord caudal to the lesion not only recovers its reflex symptoms but becomes highly excitable." He then differentiates three stages of reflex excitability after total section. The first stage is the stage of spinal shock already mentioned, with flaccid paralysis and loss of reflexes, toneless muscles, complete anæsthesia and analgesia, retention of urine and fæces, and a dry skin which readily becomes gangrenous. This condition lasts from two to three weeks and is followed by the second, the stage of reflex activity. In this stage stimulation of the sole may cause a marked flexion reflex, with dorsiflexion of the toes as insisted upon by Walshe, which may involve the opposite limb; or a still more widely spread "mass reflex," in which the abdominal wall joins in the flexion, the bladder is evacuated, and sweating occurs throughout the paralysed region. Extensor reactions are also obtainable from the ligamentum patellæ and tendo Achillis; in this stage the skin becomes more vascular, and bedsores tend to heal. After a period of many weeks or months this stage gives place finally to a third, in which the activity of the reflex centres dies out, the extensor tendon jerks, the flexion and mass reflexes and the automatic or reflex emptying of the bladder cease, the skin presents a strong tendency to slough, and death generally follows from septic complications.

These observations show clearly then that the return of reflexes below the lesion is no evidence of returning function, and they incidentally remove the false premise upon which an estimate of recovery has often been based.

On the other hand, Riddoch finds that in certain cases of incomplete lesion the reflexes differ from the typical mass reflex and conform more to a purposive type; the abdominal portion of the "mass reflex," including micturition, is absent; there is a tendency to alternation of flexion with extension reflexes or to flexion of the irritated limb with contralateral extension, that is, to movements of stepping or progression. For fuller details reference must be made to the original papers, but the broad issue for the surgeon lies in the proposition that the "mass reflex" is usually associated with complete anatomical transverse lesion, whereas in partial lesions a more purposive reflex action is observable.

Apart then from definite improvement in motor or sensory power there is, in the case of the spinal cord, even less means of determining at an early stage whether an injury is complete or partial than there is in that of peripheral nerves. One is thus in the great majority of cases faced by the impossibility of determining how far recovery is possible, and time alone will answer this question. In the case of nerve trunks this practical difficulty is diminished by the fact that delay is not a serious bar to their subsequent resection and suture. In the spinal cord, however, such methods are impracticable, and hence all that can be done is to "place the cord in the most favourable position for repair" at the earliest possible date, and then await results. For this reason it becomes almost impossible to say how far any recovery may or may not have been due to early operative treatment.

Treatment.

In view of the difficulty of defining the extent of the anatomical lesion, the question of early or late treatment by laminectomy has to be guided in the main by collateral considerations. The following propositions may, however, be regarded as almost axiomatic:—

- (1) Other things being equal, it is unwise to operate during the stage of acute sepsis.
- (2) If, however, there be evidence of thecal injury with septic meningitis the only hope lies in early drainage. Little is to be expected.
- (3) If again there is evidence that the theca is untorn, but that a foreign body or other septic mass, such as bone or blood, lies in its immediate vicinity, this is best removed at an early date.
- (4) When sepsis has ceased, if an operation is to be performed, the sooner it is performed the better.

In order to determine, if possible, the exact condition of the theca, the bones and the surrounding parts, the skiagram is of the utmost value, but great care is required in its interpretation. It has already been shown that a normal position of the bones is not inconsistent with their temporary and highly effected depression. It has also been seen that the gravest injury may be inflicted upon the cord without any fracture at all, and that fracture of outlying vertebral processes may be widely spread without implying equally wide-spread injury to the cord. Hence the X-ray picture, which should be both lateral and antero-posterior, or stereoscopic,

must be compared with the probable course of the missile as indicated by the wound or wounds. Careful examination may then enable the surgeon in many cases to arrive at a definite decision, of which the following are examples. It may be reasonably assumed that the bullet has not involved the spinal canal if the wound be anterior, the metal fragments resting in a vertebral body and the laminae uninjured, or if the wound track lies well behind the spine and a spinous process is detached with or without metal "scrapings" at the point of fracture. On the other hand, if stereoscopic or combined lateral and sagittal pictures show a metal fragment or a piece of bone inside the spinal canal, it may generally be assumed that the cord is cut across or very severely contused, and probably destroyed by hæmorrhage into its substance. Severe destruction of the vertebral bodies also implies a hopeless injury to the cord. On such grounds it may often be possible to say that an operation is useless, either because the cord is completely crushed or cut, or because the wound is likely to be remote from the cord, and the medullary symptoms have resulted solely from concussion.

In yet other cases there may be definite indications in favour of immediate operation, as for example in a case of typical Brown-Séquard paralysis, in which a large pointed metal fragment was withdrawn from between the first and second cervical vertebræ, the base of the fragment being visible in the wound. Recovery was very complete. Such cases are, however, rare, and in war at any rate there will be little time or opportunity for their early investigation. In view of the comparative rarity of successful laminectomy under any conditions, it became almost the rule in the British armies not to attempt early treatment. On the other hand, Blair points out that certain cases may advantageously be operated upon even in a casualty clearing station, and he gives incomplete paralysis, accessibility of the missile, and pain as indications for such operations. The first of these is perhaps doubtful as it may well be that the case is one which would if left alone progress to recovery. Thorburn has felt justified in operating early upon only five cases in which the missile was readily accessible, such operation being confined to its removal, and of these cases two survived and made good recoveries, while three died from the spread of meningitis in the torn theca. Apart from such comparatively rare cases it will, in the vast majority, be wise always to await the healing of the wound.

Late operations, after sepsis is at an end, have been performed in many cases but apparently not always with the same objective. The great majority of surgeons aim only at the removal of pressure, whether due to missiles, bone, hæmorrhage or cicatrices. A very few have aimed at resecting and reuniting the cord on the analogy of suture of the peripheral nerves. This type of operation will be dealt with later and only cases of laminectomy for the relief of pressure need be considered here.

The largest collection of personal cases is probably that of Marburg and Ranzl. Over 300 were admitted to von Eiselberg's clinic and of these 142 were operated upon. The chief indication was the radiographic evidence of invasion of the spinal canal by a foreign body or a piece of bone, and operation was adopted as soon as the patient appeared likely to survive. Operation was not, however, resorted to in cases of severe shock, certain complications in connection with the thoracic and abdominal viscera, advancing bedsores or cystitis and septic sinuses. Apart from radiographic indications complete paraplegia was taken as a contraindication to operation. In partial lesions improvement was awaited for two months and any arrest of such improvement or late aggravation of symptoms was taken as an indication to operate. Of the 142 cases operated upon 42 had died at the time of report, nine of the deaths being due to wound complications and five to pneumonia, yielding the rather high operative mortality of about 10 per cent. For the remaining 100 cases the following results are claimed: little or no improvement in 59; definite improvement in 41, of which 19 were rendered fit for at least some form of military service. Of the 19 which may thus be described as recoveries, in seven the bullet was found lodged within the dura mater, in seven it lay inside the vertebral canal but outside the theca, and in the others there was a fracture.

When, however, an analysis is made of these 19 recoveries,* we find that in all of those in which the bullet was found within the theca the lesion was well below the level of the spinal cord and the cauda equina alone was affected. Hence, although there can be no question as to the propriety of the operation it is by no means certain that in at least some of the cases recovery would not have occurred without it.

Again, in the group of cases in which the missile lay in the spinal canal but not in the theca we find two in which the

* See *Medical Supplement to the Review of the Foreign Press* for April 1919.

cauda equina only was implicated, while in one there is no evidence of serious nerve injury. Three cases are examples of unilateral lesion, and it is interesting to note how completely these recovered, an experience also shared by Thorburn. In one case only was there paraplegia, and in this the bladder and rectum had escaped paralysis, so that the lesion was far from being complete.

Lastly there are five cases representing a type in which Thorburn obtained the best results, namely those in which the cord or cauda equina is compressed by a mass of perithecal cicatrix due to pachymeningitis; a severe example is described in the *Journal of the Royal Army Medical Corps*, August 1918.

Several German surgeons report large numbers of operations. Keppler saw 54 cases of injury to the spinal cord, of which seven were submitted to early operation. Four of these seven died; in one, in which the cord was divided, the wound healed but there was no improvement; a wound at the level of the third lumbar vertebra with incomplete paraplegia showed only a collection of blood-stained cerebro-spinal fluid and improved after operation; a somewhat similar case was met with at the level of the twelfth dorsal vertebra. Perthes reports six early operations for wound of the spinal cord; in one there was some improvement, in one the paraplegia appeared to be increased. Krause observed 71 cases of wound of the spinal cord; he concludes that there is hardly any prospect of recovery after a wound involving the theca and even less after a tangential wound of the cord itself, while even with an uninjured dura the cord may be completely crushed. Less disastrous is hæmorrhage into or outside the theca, but even the latter may cause complete and irreparable paralysis. Compression by collections of cerebro-spinal fluid may also cause paralysis and such cases are capable of relief by operation. He advises operation in nearly all cases except where the bullet is lodged in the cord, but he admits that division of the cord is irreparable and suture of its substance impracticable.

Hughes reports seven cases of laminectomy of which four with flaccid paralysis and sphincter loss were followed by no improvement, while three of late development or exaggeration of paralysis but without sphincteric loss made good recoveries.

Walton sums up the selection of cases for operation as follows: "In early stages do not operate unless there is some sign of recovery or the lesion is incomplete, in which case the earlier the operation is performed the better. Symptoms developing at a late date are due to inflammatory exudation,

with contraction of scar tissue of callus, and operation should in these cases be performed without delay. For relief of pain operations upon nerve roots may be justifiable. Sutures and grafting of the cord are useless." To these principles early operation for accessible foreign bodies or for the provision of drainage may be added.

The following may perhaps be advanced as an example of the type of case which may be expected to give the best results from laminectomy, although for reasons not clearly explained the actual result was fatal.

The patient was admitted to a general hospital with paraplegia and a small clean wound on the right side of the neck. On admission the arms were folded on the chest and forearms supinated; all four limbs and the intercostal muscles were paralysed; there was no knee-jerk or sole reflex; urine was retained. Sensation was lost below the neck except for some vague deep sensation in the right thigh.

On the fourth day, he could feebly move all muscles of the left upper limb except those of the hand; in the right upper limb contractions could be defined only in the deltoid and flexors of the elbow; there was slight power of flexing both hips and moving both ankles; the intercostal muscles were acting feebly but distinctly; knee- and ankle-jerks were present and exaggerated; the sole reflex was extensor. Anæsthesia of the trunk extended to the level of the cervical nerves; the right upper limb was anæsthetic except on its outer side (fifth segment); the left upper limb was anæsthetic only as high as the distribution of the eighth cervical or first dorsal segment. The bladder could be emptied voluntarily. Here, then, there was a rapidly improving partial lesion of the cord and with an oblique upper limit, so that on the left side both paralysis and anæsthesia included only the first dorsal segment, while on the right they extended to the sixth cervical.

Some improvement continued for over three weeks, when it appeared to be arrested and laminectomy was then performed, the fourth, fifth and sixth cervical laminae being exposed. A small punctured fracture was found on the left side of the fifth cervical lamina, which was removed exposing an opening in the theca adherent to the spinal cord. The adhesions were separated when there was a free flow of cerebro-spinal fluid, respirations became very slow and feeble and death occurred on the operating table.

The post-mortem specimen (Fig. 7) shows a small fragment of shell and a spicule of bone, derived from the fifth cervical lamina, but lying just under the fourth. Both fragments have penetrated the theca and have been carried slightly upwards to the left of the spinal cord, which is partially divided at about the level of the sixth segment. The fragment of bone is resting in the cord, the metal applied to the theca between it and the cord. There is no meningitis and the area is apparently quite free from sepsis.

The questions of laminectomy for gunshot injuries may be summed up as follows:—

Operation may be considered at one of three periods, namely, in quite recent cases; after the earliest stage has passed away; and in late cases.

In recent cases foreign bodies obviously projecting into the spinal canal should be removed, if readily accessible. General wound toilet and drainage should be provided at once. Formal operation for paraplegia should not be undertaken.

In cases in which early symptoms have given place to the typical stage the cessation of sepsis should always be awaited. Cases which are steadily recovering should not be operated upon, unless there is clear evidence (radiological, etc.) that some small fragment of bone or missile is pressing upon the theca. Cases of fixed paraplegia, cases of obvious massive compression or transfixion and cases of displacement of vertebral bodies cannot be expected to yield any good results, unless the injury be limited to the cauda equina. Cases in which early improvement becomes arrested may advisably be explored.

Cases in which symptoms develop late are probably due to cicatricial pressure and should always be operated upon.

In all cases it is to be realized that cord tissue destroyed by section crushing or hæmorrhage is irreparable and the return of reflexes or of subjective sensations is not to be mistaken for evidence of recovery.

As an administrative procedure injuries of the spinal cord, with the rare exception of those calling for early operation, should be evacuated to the base as quickly as possible and dealt with in base hospitals. After operation they should not be moved for at least ten to fourteen days.

A few attempts have been made to suture the spinal cord, or even to insert grafts. In this connection the earlier cases of Harte and Stewart, Fowler and Estes are sufficiently well known, and it is unnecessary to return to the controversies to which they have given rise ; but it is of very great interest to note that the best described of these, that of Harte and Stewart, has recently been re-investigated by Cadwalader, who finds that after a period of eighteen years there is no evidence whatever of return of function after myelorrhaphy. Mayo Robson refers briefly to two cases, one a case of tuberculous disease with marked angular curvature followed by fracture, in which the cord was " torn nearly across ; " the spine having been straightened, the torn cord was brought together and sutured ; recovery ensued. In the second case, the cord was partly divided and " otherwise seriously damaged " by a bullet lodging in the spinal canal at a level not stated. After sepsis had subsided, the edges of the injured part of the cord were pared and a piece of rabbit's spinal cord was implanted ; some recovery is stated to have occurred after two months, but the details are wanting. A valuable and clearly open-minded description of an attempt at suture is recorded by Claude and Lhermitte. A wound in the dorsal region was

followed by complete paraplegia and retention of urine. On the following day a splinter of shell with bony fragments was removed from the cord and it and the theca were sutured. Knee jerks, defensive reflexes, automatic movements and reactions returned and were accompanied by vague sensation in the feet. After eight weeks the patient died and the cord was found completely divided, with an interval of 1 cm. filled by a dense mass of cicatrix and spiculæ of bone; the cicatrix contained no nervous tissue and there was no evidence of regeneration in either end of the divided cord. The observers conclude that myelorrhaphy is contraindicated, as it may give rise to complications and cannot possibly give relief. The case illustrates once more the fallacy of regarding as evidence of recovery either subjective sensations or reflex movements, however purposive they may appear.

Treatment of Symptoms.

Many cases of complete paralysis present severe and lasting pain, which is probably often due to pressure upon the posterior nerve roots. In some of these, operation has revealed cicatricial or bony pressure or even small metal fragments which can be removed. In others, in which paraplegia is complete and permanent, it would appear that the only possible source of relief is by division of the cord above the injury, and Krause has adopted this course using the somewhat remarkable weapon of a Pacquelin cautery, although he states that in another case he would use the knife. Relief of pain by injection of alcohol into the cord has not been observed. In any case, pithing, as more controllable in its action, is preferable. The operation of dividing the postero-lateral columns, which is less severe than that of pithing, has not, so far as is ascertained, been adopted for cases of this type.

Continued spasm—a prolongation of the “mass reflex”—is a source of great trouble to many patients, and in not a few cases is the main element in rendering the lower limbs quite useless. For its relief the operation of crushing the obturator nerves has been performed at the Tooting Military Hospital, and is based upon the ground that the most troublesome spasm is that of the adductor muscles. It is said that much relief has been given by it, but no details have been published. Borchard and Cassirer have in two cases adopted Förster's method of dividing alternate posterior roots of the cauda equina and appear thereby to have given a good deal of relief. Riddoch strongly insists on the importance, during the stage

of reflex activity, of avoiding all rough handling, of gentleness in catheterization and of treating digestive troubles which are liable to excite the mass reflex.

In cases of complete interruption of the cord or cauda equina, paralysis is, of course, permanent and irremediable, but in many cases which fall short of being complete by even a very slight degree a remarkable amount of power may return, and slow improvement may continue for a very long period of time. In all such cases therefore it is essential to stimulate to action such functions as remain. The use of massage and other similar methods of treatment here plays its part, and is conducted upon lines similar to those followed in the case of peripheral nerve injury. In some rare cases also such methods as tendon transplantation may find a place. But injuries to the spinal cord differ fundamentally from those of peripheral nerves, in that the muscles are not cut off from their neurones or reflex arcs, but that the latter are deprived of cerebral or cerebellar control. Hence there is far less atrophy and degeneration, and the necessity for and value of "local stimulation" is thereby lessened. The paths which it is essential to re-open are those from the brain to the spinal segments, and the only hope of assisting such a process is by encouraging voluntary stimulation and effort. Thus, apart from the treatment of spasm—if any be present—treatment consists mainly in educating and exercising such muscles as remain. If the patient can use his limbs at all he should be encouraged to do so freely when in bed, and whenever possible he should be got out of bed. The self-propelled wheel chair at least tends to maintain general health and metabolism, to diminish the risk of bedsores, and to allow of change and improve the *moral*, while it may enable the patient to do some satisfactory work. Still better, if it can be used, is a "go-cart," in which the patient, supporting himself by the arms and axillæ, is placed inside a hollow truncated cone on wheels and makes efforts at progression with his own limbs, although these may be still unable to carry the body weight. Also of very great value is the swimming bath, which has been largely used at Tooting; the bath is 3 ft. 6 in. in depth, is filled with water at a temperature of 92°–94° Fahrenheit, and is provided with a railing with hanging rings or bars. In it the paraplegic man can easily support himself by his arms or by the "water-wings" used in teaching children to swim, and his efforts to paddle about in the warm water are often followed by a truly remarkable recovery of partially paralysed limbs.

In cases of complete paraplegia, Krukenberg has twice practised the following operation. Exposing the anterior crural nerve in the groin, he traces it up as far as possible towards its origin, and there cutting it across brings out the peripheral end. The ulnar nerve is then exposed from the axilla to below the elbow, cut across at the latter point and implanted into a groove cut in the side of the chest and abdomen. The long central end of the ulnar and the long peripheral end of the anterior crural are then stretched, approximated and sutured together. The operator states that as a result of this proceeding one patient regained in six weeks some power of flexion and abduction of the hip, and the other regained sensation down to the level of the knees. An "anastomosis" of this type cannot however receive support from what is known of the physiology and pathology of the nervous system, and the possible fallacies in the interpretation of its alleged results are obvious.

That the great majority of patients with serious injuries of the spinal cord, other than those which involve the muscles of respiration, die from the usual sequence of events—retention of urine, cystitis, urinary sepsis—is not a recent discovery. But the surgery of the war has emphasized the importance of vesical complications in several ways. The transport of cases with retention of urine presented very great difficulties on account of the long intervals which often occurred between evacuations of the bladder by catheter. It soon became fully and generally realized that cases of incomplete paraplegia presented great powers of recovery except when vesical control was lost, but that the latter symptom called for a very grave prognosis, a point strongly insisted upon by Hughes. Head and Riddoch and others found that urinary sepsis, apart from its general bad effect upon the patient's health, prevented the return of reflex action after the stage of spinal shock, and was associated with general degenerative changes in the nervous system. Such considerations led to a careful study of the innervation of the bladder, and especially to a remarkable series of papers by Fearnside and Head and Riddoch.

In connection with treatment there arose a strong opposition to the regular use of the catheter, this opposition resulting in attempts to evacuate the bladder by pressure alone, in permanent drainage of the bladder by suprapubic cystotomy, and in the use of the "mass reflex" to procure evacuation.

Formerly, cystitis was attributed to the introduction of organisms by instruments, although a very short experience showed that the mere refusal of catheterization did not prevent cystitis, while suprapubic and perineal cystotomy were considered "too heroic." These methods have, however, now become common. In many cases the bladder contents can be "expressed" by pressure upon the hypogastrium, with or without the introduction of two fingers into the rectum to produce counter-pressure. Unfortunately, this simple method, which is probably not merely mechanical but due to stimulation of a reflex or of idiomuscular contraction, is by no means always effective in emptying the organ, and every surgeon accustomed to operations upon the bladder even in the absence of nervous disease knows that it cannot be expected to be so.

Suprapubic cystotomy, on the other hand, allows of very complete evacuation, of rest to the bladder wall, of immunity from all back pressure and of efficient lavage. It has been very freely adopted in the British armies, and was with many surgeons a routine treatment from the earliest moment after injury. The usual method is as follows: "A two-inch median incision is made and the full bladder exposed. With an ordinary sinus forceps or Spencer Wells forceps, held closed, a stab is made through the bladder wall, and the blades are then separated just widely enough to permit the introduction of a Guyon self-retaining suprapubic tube stretched on a long probe. When the forceps is removed and the probe withdrawn, the tube is found to be tightly gripped by the bladder wall and the junction to be completely watertight."* The tube is then connected with a longer rubber tube leading into a bottle attached to the bed or stretcher, and irrigation is effected by means of a Higginson's syringe, of which the nozzle is introduced into the urethra. Such a method undoubtedly presented great advantages in cases requiring transport and not under the supervision of one individual, but whether in civil practice it will ultimately supplant the careful and frequent use of the catheter with lavage of the usual type is perhaps questionable.

Riddoch has carefully studied the use of the mass reflex as a means of provoking evacuation of the contents of the bladder. He points out that in the "stage of reflex activity" the bladder tends to empty itself at fixed intervals, which vary in the case

* "Injuries and Diseases of the War," issued by the D.G.M.S., British Armies in France, December 1917, p. 120.

of the individual from two to four hours. The interval should be determined in each person, and when evacuation is about due a flexor spasm should be evoked by stimulating the abdominal wall or the lower limbs. The bladder contents are then voided; they can be collected in a urinal, and the bed is kept dry. This method of treatment, which is of course only available when the reflex is present, has the disadvantage that it is not possible in early cases or in those in which pyelitis has led to intoxication and abolition of the reflex, while it makes no provision for washing out the bladder. Its value will probably lie mainly in the less common and less serious cases in which cystitis has not occurred at an early date.

In civil practice and with good nursing the systematic use of the catheter with most careful asepsis of the instruments and of the glans penis, still presents the best method of treating retention of urine, but it is always to be remembered that "the bladder holds the key to life or death for the patient," and it is impossible to exaggerate the care required in catheterization, while in military surgery the essential precautions can hardly be consistently maintained.

Lesions of Nerve Roots.

It is often extremely difficult to distinguish affections of the spinal cord from associated injuries of nerve roots, and except in the case of the cauda equina the latter can hardly be considered apart. Hence reference has already been made to such symptoms as pain, which is very generally due to affections of nerve roots rather than to that of the cord itself.

Stopford describes five cases of injuries of the cervical nerve roots. In three of the cases there was no lesion of the cord, and in two the cord was also injured. In two cases of unilateral injury to roots of the brachial plexus there was most marked dissociation of the sensory from the motor symptoms; a third case was bilateral and was associated with a very temporary paraplegia from concussion of the cord. The cases associated with cord injury showed some definite medullary affection in addition to the root lesion. The nature of the injury to the roots in these cases is a little obscure. The fact that they present a very rapid improvement in the extent of paralysis and anæsthesia, shows that much is due to concussion; the course of the bullet rendered improbable any direct laceration, which would, moreover, almost certainly have more seriously compromised the spinal cord. Hence he regards the troubles as due to hæmorrhage, especially from

the small vessels of the pia mater. This view is also consistent with the fact that symptoms show a considerable variation even from day to day; the late supervention in some cases of spinal cord symptoms is attributed to "meningeal adhesions"—that is, to post-hæmorrhagic cicatrices, which probably play no small part in other and graver injuries of the cord. Collier also refers to root lesions, due to pachymeningeal hæmorrhage and periosteal hæmorrhage, in which the symptoms of pressure on the roots may overshadow those of any lesion of the cord. The diagnosis of these cases from injury of the brachial plexus may present the greatest difficulty, but can usually be effected by noting at some period a slight involvement of the spinal cord. The prognosis is comparatively good, as might be expected from the assumed pathology and the proximity of the lesion to the trophic centres of the involved axons. Apparently the main permanent inconvenience is likely to be pain, which might call for posterior root section.

Root lesions in the dorsal region do not appear to have been described as apart from other conditions, and judging from the cervical cases, they would be very inconspicuous and would rapidly recover. Here, however, as elsewhere, severe pain may be due to the coincidence of such with lesion of the spinal cord.

Injuries of the cauda equina, on the other hand, have been very frequent during the war, and it has been seen how many of the cases submitted to laminectomy with a favourable result have been of this class. The differentiation of such injuries from those of the conus medullaris has received much attention, but no new facts have been made manifest. It is a little remarkable that not a single example has been met with in which the cauda equina has been sutured. This obvious and rational proceeding was adopted by Tuffier many years ago, and has been constantly referred to by later writers. Unfortunately, in gunshot wounds there is generally so much scar tissue calling for excision that end-to-end approximation is impossible, while the anatomical relationships of the cauda equina will always prevent any material stretching, and thus end-to-end union of its roots can only be hoped for in the case of very small gaps. Again, it is to be noted that a graft placed in the cauda equina occupies a different, and probably disadvantageous, position as compared with one in a peripheral nerve, as it will lie on the central side of the posterior root ganglia, and in the face of the very doubtful value of even

peripheral grafting the outlook for such operation is by no means hopeful.

Several cases of such extensive gaps in the cauda equina were operated on, but without success. In the earlier examples, after relief of all pressure the scar tissue or interval was left untouched; in a recent instance of three years' total paraplegia a piece of the patient's sciatic nerve two inches long was implanted into the gap, not with any valid hope of success but on the ground that at least no harm could be done and that some continuity might be obtained, but thus far no beneficial results have been observed.

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CHAPTER V.

INJURIES TO THE PERIPHERAL NERVES.

INJURIES of the peripheral nerves were extremely common during the war, and it is estimated that of all serious battle casualties about 20 per cent. showed at least some injury to important nerve trunks. The resulting symptoms were often so serious, their treatment presented such special difficulties and demanded so great a length of time, that it was found necessary in most of the countries engaged in the war to collect large numbers of these cases into special hospitals. In France this was done from an early date, in the United Kingdom arrangements with this object were made in the early part of 1915, and eventually several hospitals were largely used as special institutions for the treatment of injuries to nerves.

The whole subject of such treatment was thus reinvestigated, and many valuable lessons were learned. To realize the advance made, it is only necessary to read the reports of a meeting of the Medical Society of London, held in November 1915, or the observations of Benisty as to the confusion of ideas and doubts with respect to treatment which obtained in France during the early months of the war, or to turn to the analysis of German literature published in the Medical Supplement to the British Daily Review of the Foreign Press for October 1918, and to contrast the conditions at first with the fairly well-defined rules which were laid down subsequently.

Nature of the Nerve Injuries.

The strain of campaigning led to the evolution of certain affections of the peripheral nerves which might otherwise have caused little inconvenience. Thus surgeons observed in France a considerable number of cases of compression and irritation of the brachial plexus by cervical ribs, which were liable to make themselves felt either from hard physical work or from such special causes as the use of the shoulder strap or other equipment. Apart also from battle casualties, accidents were common; and such affections as ruptures or contusions of the brachial plexus, dislocations of the ulnar nerve, and the like, were not uncommon. But these injuries naturally presented no essential differences from types familiar in civil surgery.

Sabre and bayonet wounds were rare, although a considerable proportion of accidental bayonet wounds was met with. In all such cases the incisions or stabs presented no special features, and the divided ends were usually not far apart; the wounds were seldom highly septic, and primary suture could be practised in most cases as in the wounds of civil life.

It is therefore only necessary to consider gunshot wounds, including those of bullets, shrapnel, high explosive shell, and missiles in which the so-called explosive or divulsive element plays an important part. These injuries were met with in varying proportions in different campaigns and at different times, according to the type of warfare. Thus it was noticeable in France that after August 1918 wounds from rifle and machine-gun bullets became more common than they had been previously in trench warfare.

The following classes of injuries have been observed.

(1) Those due to the direct impact of a rifle or machine-gun bullet of high velocity. These caused an injury which approximated to a clean section; sepsis was comparatively slight or might be absent; gas gangrene was rare; the nerve might be merely perforated or cut across in part only. When section was complete the ends were seldom far apart, although the divulsive action of the bullet produced more widely spread damage than that which results from section by a cutting instrument.

(2) Those due to the impact of fragments of shell, of shrapnel bullets, and of other missiles of comparatively low velocity but often of considerable mass, were of greater extent. The nerve in these cases might be contused or crushed without loss of mechanical continuity; it might be torn through, its ends being quite widely separated, or a section of it might be entirely blown away. Sepsis was more severe and gangrene more common than in the injuries caused by rifle or machine-gun fire.

(3) Indirect injuries due to the scattering of fragments of bone. Mechanical injury tended to be less than in the second group but sepsis was generally severe.

(4) Contusions without any direct impact of metal or of bone, resulting merely from the displacement of soft parts. In slighter cases there might be no discoverable anatomical change, and loss of conductivity due to concussion was usually soon repaired.

(5) Compression subsequent to that of the original wound, due to cicatrices and occasionally to bony callus or aneurysms.

The following conditions might thus be produced at the time of injury :—

Complete section with more or less wide separation of the cut ends, this being found according to Benisty in only 22 per cent. of all cases which reached base hospitals ; partial section, in which some fibres only are divided by " attrition," while the rest of the nerve is anatomically intact but, in many cases, full of blood-clot ; hæmorrhage into the nerve substance, without loss of continuity ; complete interruption of physiological continuity, without any obvious anatomical change.

More important for the surgeon were the local conditions met with after a month or two, when secondary operations are likely to be required, and when it is essential to know whether the exposed nerve is or is not capable of recovery. In such cases the conditions met with were as follows :—

(1) Complete separation of the cut ends, with a varying interval, the proximal end presenting the typical end-bulb, and the distal with a smaller bulb or with none at all.

(2) A similar condition in which the two end bulbs are held together by a band of cicatricial tissue.

In both of these conditions there is clearly complete anatomical loss of continuity.

(3) Partial section, with a distinct lateral notch showing bulbous formation, especially at the proximal side, and often showing cicatricial changes in the intact portion of the nerve.

(4) Partial section or perforation with a fibrous nodule, which may be central or lateral, and is also liable to accompanying sclerosis.

In these two conditions there is no complete anatomical separation, but physiological loss of continuity may be complete or partial.

(5) No form of mechanical division, but sclerotic changes with local degeneration of nerve fibres.

(6) No microscopic changes of any kind, except small areas of hæmorrhage and degeneration.

It is in these two conditions of merely physiological loss of continuity that it becomes most difficult to estimate the capacity for repair.

(7) In some cases foreign bodies, such as metal fragments or pieces of bone, may intervene between the ends of wholly or partially divided nerves.

(8) In cases of compression, the nerve is impinged upon or surrounded by cicatrices, callus, or a traumatic aneurysm, and in such cases it may be much thickened and often very

sharply strangulated, while occasionally parts are swollen and œdematous.

The following analysis by Joyce of the relative frequency of injuries discovered at operation in 90 cases, may be regarded as fairly representative of the above conditions at the time when secondary operations are likely to be required.

Complete section	34
Neuroma	9
" with lateral or central cicatrix..	22
" " lateral notch	4
" " involvement in callus	4
Lateral notch with neuroma	3
" " " involvement in callus	2
" " " scar	3
" " " deformity of bone	2
Foreign body in the nerve	1
Pressure of aneurysm	4
Contusion	1
Nothing abnormal	1

As regards the incidence of injury in various nerves other than cranial nerves, an analysis of the combined figures of injuries recorded by Tinel (639 cases), Stewart and Evans (466), Souttar and Twining (123), Renfrew White (64), and Joyce (147), gives a total of 1439 cases treated in various hospitals and under varying conditions. Amongst these 11 only involved the cervical plexus and trunk and 961 concerned the nerves of the upper extremity.

Cervical plexus.. .. . in	6 cases.
Nerves of the trunk "	5 "
Musculo-spiral, radial, and posterior interosseous "	270 "
Ulnar "	227 "
Median "	148 "
Brachial plexus "	147 "
Circumflex "	28 "
Musculo-cutaneous "	18 "
Other nerves of the upper limb "	9 "
Combined injuries "	114 "
In the lower extremity 467 nerve injuries were recorded.	
Sciatic in	154 cases.
External popliteal "	105 "
Internal popliteal "	39 "
Lumbo-sacral plexus "	29 "
Posterior tibial "	28 "

Cauda equina	in	21 cases.
Internal saphena	„	21 „
Anterior crural	„	19 „
Musculo-cutaneous	„	11 „
Anterior tibial	„	5 „
Obturator	„	3 „
Other nerves of the lower limb	„	19 „
Combined injuries	„	13 „

It will be obvious that these figures, obtained from base hospitals, do not accurately represent the full proportion of cases with injuries to the nerves of the lower limbs, as many of these would be unable to reach the base.

Pathological Considerations.

A certain amount of experimental work, especially in connection with the stimulation at the time of operation both of divided nerves and of adjacent healthy nerves, has shown that much regularity obtains in the distribution of fibres destined for the various muscles served by the nerve. The fibres for individual muscles can thus be traced far up the nerve trunk, and from observations by Stoffel, Marie, Meige and Gosset, Déjérine and Putti, it is important to note that they appear to lie in a spiral course like the strands of a rope, and not to run vertically, a fact which increases the difficulty of obtaining correct apposition at the time of operation.

As regards the regeneration of nerves, there is now almost complete acceptance of the view that regeneration is only produced by the downgrowth of axons from the proximal end into sheaths at the peripheral end, which have previously prepared themselves for the reception of the new axons by degeneration of their own contents. The peripheral neurilemma sheaths show regenerative changes, but such concern only the protective coverings for the axons, which always enter the periphery from above, as taught originally by Waller, Ranvier and others. The importance of a clear conception of this fact in connection with operative procedures is very great. In order to obtain physiological or neurological recovery after section, it is essential that proximal axons should grow into the distal sheaths for which they were originally intended. The proximal axons always retain their association with motor or sensory neurones in the spinal cord; the distal neurilemma sheaths always retain their connection with motor or sensory terminals at the periphery; hence if motor axons enter sheaths which lead them to sensory terminals, or

if afferent axons enter sheaths which lead them to muscle endings, there will be no physiological result at all, and such axons will be lost for ever. In the same way, if motor axons intended for a given muscle become connected with the peripheral sheaths of a different muscle, confusion will result; and if sensory terminals become connected with wrong sensory neurones in the spinal cord there will clearly be a lack of correct transmission. Thus, then, it must be realized that in order to obtain repair of a nerve it is necessary not only to produce anatomical continuity of its two ends, but to avoid any shunting of its internal arrangements; such shunting will lessen or destroy the physiological value of the most perfect operation. The physiological error is no doubt capable of great improvement by re-education on the part of the nervous system, but such re-education is a tedious process, and rarely if ever perfect.

A consideration of the above propositions will indicate that many of the older types of operation for injuries of nerves could never be expected to yield any functional result, and experience has shown that these older operations were valueless. As however some of them continued to be practised in the early part of the war, it is advisable to refer to them if only to emphasize that later experience has shown their futility. Vanlair endeavoured long ago to unite the two ends of nerves which could not be brought into contact by means of rubber tubing and decalcified bone tubes. Lewis and Kirk in experimental work on animals made large gaps in nerve trunks, which were bridged by tubes of autogenetic fascia wrapped round the two ends. In their work the fascial tube was found to remain patent, and axis cylinders grew down into it from the proximal towards the distal end of the nerve. In man, Platt and Stopford of the Grangethorpe Military Hospital, Manchester, adopted a similar method in 17 cases in which end-to-end suture was impossible. They used in every case the fascial tube; in eleven they also used an autogenous nerve graft placed within the tube and sutured to the two ends; in six two strands of catgut were included instead of the graft, and in all the tube was finally filled with sterilized olive oil. In none of these 17 cases was there any clinical sign of regeneration after periods which extended up to three years. In several the bridged gap was eventually excised and examined, and in only one was there any downgrowth of nerve tissue into the tube; in this last the graft had been penetrated by axis cylinders for about half its length. In Germany a similar

method was adopted by Hohmann, Spielmeyer, Enderlen, Lobenhoffer and Edinger, but the results were all negative. Although therefore Lewis and Kirk appear beyond all doubt to have obtained some downgrowth in the case of animals, there is no evidence whatever of such in the case of man. Operations which depend upon the insertion between the nerve ends of a neutral conducting tube must therefore be discarded.

Similarly, to split the proximal end of a nerve bulb and turn down a flap of half its thickness does not bring growing axis cylinders into connection with empty neurilemma sheaths, and although this form of "plastic operation" was somewhat freely adopted in the early phases of the war, it has since been given up. And again the so-called "lateral anastomosis," or lateral implantation of cut nerves into adjacent healthy nerves, has produced no effect beyond that of damage to the healthy nerve; such lateral anastomosis entirely fails to produce the correct shunting of axis cylinders into their prepared sheaths. It is unfortunate that the word anastomosis has not been altogether abandoned. It gives a totally wrong impression that hollow channels are connected with other hollow channels, whereas the union of nerves is much better described by such terms as shunting, or *aiguillage*, which express the linking together of solid fibres, as in the case of railroad lines or of electric cables.

Symptoms.

There is a large amount of literature relating to the symptoms produced by nerve injuries, but no great addition has been made to previous knowledge except in relation to minute points of anatomy and the like, for which reference may be made, amongst others, to the report of the Medical Research Committee and the papers of Stopford. It is obviously important to be able, if possible, to determine at an early date whether the paralytic results of a nerve injury are due to anatomical loss of continuity or to merely physiological loss of conductivity; and it is also important where possible to determine at an early date how far an existing condition is or is not capable of spontaneous recovery. From this point of view, symptoms in connection with electric reactions have been most carefully studied, especially by Benisty, Tinel and other French observers, but they have provided no reliable criteria. Eve and Woods, and especially Hernaman-Johnson in the early days of the war, laid much stress upon the precise mathematical registration of electric changes by means of a

Lewis-Jones condenser, but in this, as in other respects, it has not been found practicable to arrive at any definite conclusion as to the probable permanence of symptoms.

It is therefore now definitely recognized that symptoms of complete paralysis and anæsthesia may or may not be susceptible to recovery, and that time alone will decide the question. Hence it is necessary to record the early symptoms in detail, and to make examinations from time to time with a view to observing whether or not recovery is in progress. As a matter of probabilities it is estimated that in at least half of all the cases of complete paralysis after nerve injury a large amount of recovery or even complete recovery will occur. Tinel estimates such recoveries at 60 to 70 per cent.

It is, however, important to note certain symptoms which have been found to indicate the commencement of recovery. One of the most valuable of these is the so-called "Tinel's sign," or tingling of repair (*fourmillement de restauration*). On pressing or tapping the injured nerve at the site of the lesion there is produced a tingling which is often described by the patient as resembling the passage of an electric current. As long as this sensation is confined to the region of injury it indicates that no downgrowth of axis cylinders has occurred; but if it is obtainable by percussion or pressure below the lesion, it proves that at least some repair is in progress. Tinel claims that the following rules are entirely reliable:—

- (1) Fixity of the tingling on a level with the lesion indicates complete interruption, degeneration of the peripheral end and total lack of repair.
- (2) Migration downwards of the point at which formication can be evoked indicates repair, and defines the progress of the downgrowing axis cylinders.
- (3) If the downward progress of the formication point is arrested, it is an indication that repair is arrested.
- (4) Total absence of formication either at or below the lesion indicates imperfect regeneration due mainly to general disturbances of nutrition.

In brief, formication is produced only when one presses upon or percusses a point where there are actively growing axis cylinders. Incidentally it may be noted in this connection that the rate of downgrowth of the irritable area, and therefore presumably of axis cylinders, is estimated by Tinel at about 1 mm. or occasionally 2 mm. per diem.

Other indications of commencing restoration of the nerve are subjective sensations by the patient, who may say at an

early date that the part "feels different," or "feels more life in it"; restoration of muscle tone, the change in a large muscular mass being readily felt by the surgeon; attempts at contraction evoking a thickening of the muscle bellies, which may be detected before there is any evidence of longitudinal contraction; and voluntary effort, which tends to produce muscular contraction at an earlier date than does the Faradic current.

Treatment of Loss of Continuity.

Loss of continuity may be treated, according to circumstances, by the following methods:—

- (1) Primary suture.
- (2) Secondary suture.
- (3) Expectant treatment, either during recovery or while awaiting operation.
- (4) Orthopædic and educational treatment after partial or complete recovery.
- (5) Plastic operations for incurable paralysis.

The practical conclusions, which appear to have emerged from the experiences and controversies of the war may be summarized as follows.

Primary suture.—Primary suture of divided nerves is, as it always has been, the ideal method of treatment; but it is seldom possible in war, in view of the fact that it requires much time and attention to detail as regards the operation, and because absolutely aseptic wounds are rarely met with except in the case of incised wounds and are not to be hoped for after injury by shell. The operation itself differs in no way from that which was practised in civil life before the war.

The early treatment of septic wounds is governed by other considerations, and will generally involve a more or less free excision of damaged tissues. In such excision large nerves may be exposed and may or may not be found injured. When they present no anatomical signs of injury they must be respected; no detailed investigation is called for or permitted; they should be allowed to remain intact even if they form bridges across the gaping wound, and drainage tubes should be so arranged as not to press upon them. Foreign bodies, fragments of bone, and the like, in their vicinity must obviously be removed. Again, if the ends of the nerve are found to be divided, no attempt should be made to suture them in the septic area, as the operation is certain to fail, and will merely inflict further damage upon the trunk. If, however,

there is an extensive gap, the ends may be approximated by tying a ligature round each, then stretching them somewhat and tying the ligatures together, a procedure frequently adopted in Manchester in the later stages of the war. The nerve will, of course, be destroyed to beyond the level where the ligature has been applied, but as this area is already badly damaged, little or no loss is incurred thereby, and subsequent secondary operation upon the nerve will be assisted by the early approximation.

Secondary suture.—The question of whether and when secondary suture will be required is one calling for careful consideration, but the following data may be regarded as established.

Such operations should never be undertaken in the presence of obvious septic infection, however slight.

After septic infection has apparently ceased and the wound is healed, there remains a period of latent infection of uncertain duration, but seldom exceeding two months. In order to avoid the danger of operating during this latent period, it is very advisable to precede such operation by a short period of massage and local application of heat, which will tend to stimulate to activity any residual infection. Goadby suggests as a precedent to operation the use of a polyvalent streptococcal vaccine.

Secondary operation should not be undertaken until there is a reasonable certainty that spontaneous recovery will not ensue. The determination of this matter will depend in the first place upon the careful investigation and frequent re-investigation of symptoms with a view to ascertaining whether any improvement is in progress or whether early improvement becomes arrested. If no such improvement is discoverable, an arbitrary period of delay will be established, and most surgeons are apparently in agreement that about two months is a sufficient interval.

On the other hand, undue delay is unwise for economic and social reasons, and possibly because it may decrease the probabilities of ultimate success. The evidence obtainable from a large number of nerve wounds shows, however, that delay extending up to a period of at least a year has little if any effect upon the ultimate result. Very long intervals, such as those exceeding a year or more, are probably harmful, as degenerative changes tend to occur in the central nervous system.

Secondary suture may be contra-indicated by certain grave

collateral conditions, such as ununited fractures, seriously damaged joints, great loss of muscle, or wounds of such extent as to show that very large pieces of nerve have been removed. In such cases amputation will generally be called for. In cases where ununited fracture and a nerve lesion are associated operation upon the fracture should precede that upon the nerve, both because delay is more harmful in the case of the bone, and because nerve suture in the presence of ununited fractures has given bad results.

It having been decided that secondary operation is called for, it must always be regarded as in the first instance exploratory, and its final nature will depend upon the condition found; but certain general principles must be adhered to in every case. A general anæsthetic will be required, no form of local nerve blocking being permissible. The most rigid asepsis is essential. Incisions should as far as possible avoid old scar tissue, which is liable to latent infection. Hæmorrhage should be most carefully arrested, and if the wound is not perfectly dry or if there be any large "dead space," drainage should be provided for twenty-four hours after operation.

The advisability of using a tourniquet is disputed. It greatly facilitates a difficult dissection, but it must not be used unless it can be placed so far above the wound as in no way to interfere with any necessary stretching of the nerve. The objection that it causes delayed flushing of the wound with blood appears to be exaggerated, and can be overcome by its removal immediately after the nerve ends have been exposed, or by drainage. It is contended that the use of the tourniquet may lead to pressure paralysis, but this is at least unlikely to result unless it has been too tightly applied. The routine use of the tourniquet is advisable when there is room for it, as it diminishes manipulation during the necessary dissection.

The incisions used should be long and free, and may call for the transverse division of such muscles as the gluteus maximus, or the detachment of muscles from the shoulder girdle or resection of the clavicle. The dissection and exposure of the nerve should be commenced at points remote from its injury, and the two ends can then be very carefully traced towards the lesion. If it is necessary to retract the exposed nerve or to raise it above the surrounding tissues, this should be most gently done on well-rounded hooks or on loops of gauze or drainage tubing; forceps should never be used.

The nerve ends being thus exposed, it will be decided what further steps are required. If they are united by a structure

which may be purely cicatricial or may contain nerve fibres, the first step will be to ascertain the conductivity of the bridge by means of a bi-polar Faradic exciter, using preferably a Bristow coil and a minimal current. By such means all doubtful cicatricial bands should be investigated, and those which prove to contain nervous tissue should be carefully respected. Other methods have been adopted for determining the permeability of a nerve cicatrix, such as cutting out fragments for histological investigation, and the injection of a solution of methylene blue into the proximal end to ascertain whether it passes the obstruction; but these methods are undoubtedly inferior to that of Faradic excitation.

If the nerve ends are not held together by any tissue, or if the cicatrix clearly contains few or no nerve fibres, resection and end to end suture should be aimed at. All dissection should first be completed, and cicatricial tissue should be removed as far as possible. The nerve should be gently stretched in order to diminish tension, and at this stage, if necessary, the finger may be introduced into the wound to sweep round and free large trunks such as the sciatic. The nerve itself should be treated with the utmost gentleness, and should never be picked up with forceps except at a point which it is intended to excise. The limb is then adjusted in such a position as to give the fullest relaxation; and if it is considered necessary to alter the position of the nerve bed, this also is done before resection. Such alteration of position is most generally adopted in the case of the ulnar nerve at the elbow, the course of which may be much shortened by transferring it from the back to the front of the internal condyle; little, if any, room is gained by transferring the musculo-spiral to the inner side of the humerus.

Only after all these stages of the operation have been completed are the nerve ends to be resected. The proximal end is picked up and is cut across with a very sharp knife or razor blade, successive sections being made through the neuroma until bundles of nerve fibres are clearly seen. Any less resection is bound to fail, as it leaves the growing axis cylinders enclosed in a cap of fibrous tissue, and increasing boldness in resection has characterised the work of most surgeons during the war. The peripheral end is then similarly cut away, but its resection should be less extensive. It is often convenient to adopt a suggestion of Daw, that resection should at first be carried only two-thirds of the distance across each end of the nerve, the exposed portions being sutured together before the

remainder is excised. In this way there is less risk of producing rotation and bad shunting of the axis cylinders.

For suture the finest needles should be employed, and the majority of surgeons agree that catgut should be the only material. Kennedy and others prefer horsehair or fine silk, which are easy to work with ; but there seems to be no doubt that an absorbable suture gives better results. The sutures should be passed through the sheath of the nerve, and transfixion of the whole trunk should be avoided whenever possible, as end-results are found, according to Stopford and Sargent, to be less satisfactory when a tension suture has been used. In tying the sutures the two nerve ends should not be pressed together so as to evert their fibres. Contact alone should be established, and if anything a slight gap is better than mutual pressure.

There will then remain the question of surrounding the junction with some covering, so as to prevent adhesions and to obviate the spreading out of axis cylinders. For this purpose, large veins, strips of fascia or fat taken from the patient, wax, cargile membrane and so on have been employed, but in the later operations of the war the tendency was to discard all these measures. In many cases later operations have shown that nerves thus enclosed presented cicatricial masses at least as large as those in which no protective covering has been employed, and cargile membrane has been found as a loose foreign body around the nerve. On the whole the wisest course appears to be to rely on the careful cleansing of the wound, complete hæmostasis with drainage if necessary, and leaving the nerve if possible in a muscle bed. In cases such as that of the external popliteal at the knee joint, the fact that it is difficult to provide a satisfactory bed for the nerve appears to militate considerably against a good ultimate result.

The wound is then closed and the limb fixed in the position of the greatest relaxation. It is important that such fixation should not be maintained for too long, as it interferes with subsequent orthopædic treatment. Souttar and Twining remove all restraint after a week or ten days, trusting the residual stiffness of the limb to last about an equal period, and expecting that the union of the nerve will, after three weeks, be sufficient to withstand all voluntary effort. They have obtained very good results, but many surgeons have employed a rather longer period of fixation without apparent injury.

Should the injured nerve show no complete breach of continuity, but present a lateral or central neuroma, it must

be carefully investigated with the Faradic exciter to ascertain how much of its thickness requires resection. The neuroma or other tissue which appears to be purely cicatricial should then be excised and the two partially divided ends brought together as in the operation of end-to-end suture, the uncut portion of the nerve being thereby allowed to fold up upon itself. It is to be remembered that the mere excision of a neuroma without approximation of the raw ends does not effect the essential object of bringing axis cylinders into empty neurilemma sheaths.

At an early period of the war the operation of *hersage* (harrowing or combing) was fairly widely adopted, especially in France. It consists in scratching or incising longitudinally the surface of the nerve; but it is difficult to see how this proceeding can assist the proper downgrowth of axis cylinders, while it tends both to allow the lateral escape of axis cylinders, and to increase the prospects of cicatricial adhesion. In cases of recent hæmorrhage into the nerve it may be of value by allowing the escape of blood; otherwise it is not likely to be used in future.

There remain for consideration cases in which after resection and the complete removal of cicatrix the ends cannot be brought together, even after adjustment of the limb or transplantation of the nerve. In some of these cases a "two-stage" operation should be adopted, *i.e.*, before resection of the nerve ends is completed these may be tightly sutured together and the wound left for a week or ten days, when it will be found that the nerve has stretched sufficiently to allow of the completion of the original operation. Failing this, the only alternatives are to shorten the limb by excision of a portion of the bone, or to insert a graft between the cut ends of the nerve.

Shortening of the limb is most likely to be useful in the case of extensive nerve injury about the elbow joint. In such cases it is possible to obtain a useful limb by excising a sufficient length of the shaft of the humerus; but the number of cases thus treated appears to have been very small, and there are no materials for forming a judgment as to ultimate results. In the case of the lower limb the operation is most unlikely to be of value.

If it be decided to use a nerve graft, the graft is almost invariably taken from a healthy nerve of the patient. It is rarely practicable to provide it from the healthy nerve of another human being, and the use of grafts from animals

presents little, if any, prospect of good results. As donor nerves the radial in the forearm, the musculo-cutaneous in the leg, or the internal saphenous in the thigh are usually employed. Their resection involves no paralysis, and it may be possible, after having removed a sufficient amount for the purposes of the graft, so to stretch the donor nerve as to effect a primary suture. In the case of large trunks the diameter of the graft is generally too small for the gap, and in these circumstances it is necessary to use two or even more pieces side by side; while in every case the implanted fragments must be sufficiently large to bridge the gap without trace of tension. In all other respects the methods of operation are identical with those of ordinary secondary suture. It is, however, to be noted that in the case of nerve grafting it is quite impossible to control the shunting of axis cylinders from the upper to the peripheral end. The downgrowing axons are left to find their own way into the neutral sheaths of the graft, to penetrate these, and then again to find their way into the neurilemma sheaths of the periphery. Having regard to the complicated passages involved, and especially to the tendency of nerve fibrils to run a spiral course, the probabilities of error are obviously great, even if the results should appear to be anatomically successful.

With regard to the results of secondary suture of nerves, it is particularly difficult to obtain completely reliable data. Of 100 cases of suture or grafting, Tinel had 14 complete failures, 22 with practically complete recovery, and 64 which were regarded as improved. Daw states that 40 per cent. of his cases showed signs of returning motor power after seven months. Dumas investigated 115 cases which he operated on for gunshot wounds of the musculo-spiral; he claims evidence of recovery in 42 per cent. of these, and of at least some regeneration in 65 per cent., the remaining 35 per cent. being presumably entire failures; but some of his cases were treated by older and now condemned methods, such as splitting and turning down the end bulb. On the other hand, it is to be noted that the musculo-spiral nerve probably gives better results than any other. Joyce found that of 36 cases of secondary suture of various nerves 8 recovered, 6 were considerably improved, 8 presented some improvement, and in 14 there was no result. Souttar and Twining found that of 61 cases of suture 7 recovered, 32 were recovering at the time of report, 7 were doubtful, 2 were failures, and 13 were not traced; but their results, like those of Joyce, would probably

be improved by a later report, as in many cases the time elapsed had not been sufficiently long.

Platt and Stopford have carefully investigated 271 cases treated at the Grangethorpe Military Hospital, Manchester, and conclude that : " In none of the cases of secondary suture can the result be described as perfect. At the best there has been a perceptible difference in power when comparing the two sides, and at least an incomplete recovery of epicritic sensibility, even after three and a half years from the date of operation. Recovery of sensation has been particularly disappointing." Of sutures in the upper arm the total failures amounted to 12 per cent., and in the forearm to 24 per cent. At both levels recovery of voluntary power in muscles supplied by the nerve has been much less in the distal than in the proximal part of the limb.

On the whole, it may be concluded that a good functional result is to be expected after secondary suture of the musculo-spiral nerve. The extensors of the wrist usually regain full power, and the extensor communis digitorum recovers satisfactorily ; but the extensors of the index finger and thumb are much less perfect. As regards the median nerve, in a large proportion only incomplete recovery of protopathic sensibility has occurred, and voluntary power in the abductor brevis pollicis has only been found in 45 per cent. The ulnar nerve is particularly disappointing, and recovery of voluntary power in the small intrinsic muscles of the hand was exceedingly poor. These remarks apply to cases which date back for a period of three years. Still further lapse of time may improve them, but will also tend to confuse the issue by admitting of improved vicarious function.

Thorburn, summing up at the Cambridge Meeting of the British Medical Association, 1920, concluded that :—" These figures, which are by no means easy to compare, leave upon my mind the impression that secondary nerve suture gives very good results in somewhere between one-third and two-thirds of all cases ; but the most careful study of the original articles, as well as my personal experience leads me to believe that a perfect neurological recovery is rarely if ever obtained. Permanent disability may be masked in various ways, but it is almost invariably to be detected if carefully sought for. Complete failures are by no means uncommon, and must be looked for in a very definite percentage of even the best operations. If a surgeon obtains 50 per cent. of really good economic recoveries from secondary nerve suture he is doing well ; if

he obtains 75 per cent. of such recoveries which will bear investigation, his work is both brilliant and successful."

As regards the results of nerve grafting, there is no large collection of cases available. Spriggs, Jocelyn Swan, Welby Fisher and others report a certain number of successes, but there is certainly a very large number of unreported failures; and the investigation carried out by a committee of the Medical Research Committee records that "bridging of the gap with a piece of nerve, whether living or alcoholised, is justified on histological grounds, by experimental work on animals, and by a few clinical cases of very imperfect recovery; but in the present stage of our knowledge grafting should be regarded as a last resort."

Expectant Treatment.—In all cases of nerve section there will be a waiting period, either while recovery is hoped for or until the best time for operation has matured, or again after operation while waiting return of function. During this period paralysis or even mere loss of muscular tone is associated with postural deformities, such as wrist drop, foot drop and the like. Such deformities are liable to produce not only permanent stretching of the paralysed muscles and contraction of their opponents, but also secondary changes in joints and ligaments; and hence, even if a secondary operation is successful, the part is much crippled. It is therefore essential that in all cases such postural deformities should from the outset be prevented by suitable apparatus. For this reason the presence of nerve injuries should be notified at the earliest moment possible, and postural treatment should be commenced before the patient is sent to the base. The most important examples of such treatment are the supporting of the wrist in hyper-extension for musculo-spiral or posterior interosseous paralysis, and the prevention of foot drop.

The medical officer should also from the first combine with postural treatment the protection of the limb against fresh injuries, such as occur from hot-water bottles and the like, by carefully wrapping it up in cotton wool and giving due indication to the base of the nature of the case. At the base hospital similar treatment will have to be continued, and the greatest care must always be taken to prevent even the most temporary stretching of the paralysed muscles.

Almost equally important with the prevention of stretching are stimulation of the muscles by massage or electricity and the movement of joints. It is advisable that every affected joint should be moved once a day, but care must be taken to do

this without stretching. For example, in the case of injury to the musculo-spiral nerve the hyper-extension splint need not be removed from the wrist while individual fingers are being flexed; and the fingers should be kept in strong extension while the wrist is being moved. Massage must never be employed over recent cicatrices, in which septic infection might thereby be relighted.

The electric stimulation of muscles improves circulation and causes contraction of their bellies, but there is little, if any, evidence that it hastens regeneration of the nerve. The mildest effective current should be used, the Faradic, especially with the Bristow coil, being employed when it gives a reaction; or a weak galvanic current with a metronome may be adopted when there is no Faradic response. A few contractions daily will suffice for each muscle, and great care must be taken not to stimulate healthy muscles and thereby throw an extra strain on their paralysed collaterals.

In the case of the small muscles of the hand little can be done by splinting, massage or even electricity; but much can be done by the early encouragement of the patient to make every voluntary endeavour to use the fingers.

Warmth to the affected parts is of great value; they are covered by gloves, sleeves or other garments which also serve to protect anæsthetic areas from injury. The whirlpool bath, and attempts to move the limb while it is being soaked in hot water, have given very good results during the war; while at Tooting Military Hospital, as already noted, the use of the swimming bath in cases of paralysis of the lower limbs has had a similar beneficial effect.

The wider recognition of the importance of such local treatment of the paralysed and anæsthetic areas has been one of the most important lessons of the war; and it is the more to be insisted on as it must be commenced from the earliest moment, and should be prescribed by every medical officer, even before the surgeon or neurologist comes upon the scene.

Orthopædic Treatment.—This is little more than an extension of the above methods to the later stages of convalescence. It aims at providing support, accompanied by such exercise as is possible (the use of supporting bands, hinged splints, elastic traction bands, graduated exercises, and the like), the regular use of the affected part, and also the moral uplifting of the patient. Games which employ the fingers, such as draughts, halma or puzzles, apparatus to allow the use of the limb while supporting only such joints as cannot be left to themselves

(elbow splints, knee splints, wrist and shoulder splints) are all of value and may lead up to useful work. Apparatus which causes regular and increasing movements by means of a pendulum or fly-wheel is employed for stiffness of the larger joints, but in no way replaces the value of intelligent efforts. Hospitalism should be avoided as far as possible, and the patient should at the earliest moment engage in useful or at least interesting work.

Plastic operations.—Reference has already been made to operations upon nerves, and to the shortening, if necessary, of the affected limb. In cases of incurable paralysis there are however certain plastic operative measures which often prove of great value. Tendon transplantation, or attaching the tendons of healthy muscles to those which have been lost, may be employed to counteract a permanent paralysis. Thus, in paralysis of the musculo-spiral and posterior interosseous nerves, the intact flexor carpi radialis may be attached to the extensors of the thumb and first finger, and the flexor carpi ulnaris may be brought round and fixed to the tendons of the three inner fingers. The pronator teres has also been attached to the long and short radial extensors of the wrist. Similarly, in paralysis of the external popliteal nerve or its branches, the tibialis posticus can be inserted into the tibialis anticus or common extensors of the toes. In the leg the results are, however, less satisfactory than in the arm, as there is seldom enough "muscle power" to yield a vicarious supply. This method of vicarious repair has long been used by Robert Jones and others in cases of infantile paralysis. In injuries to peripheral nerves it is adapted to cases in which suture operations have failed, to extensive defects of such nerves as the musculo-spiral and external popliteal, in which the limb cannot be shortened to allow approximation of the cut ends, and to such cases as that of the posterior interosseous in the forearm, in which the nerve breaks up into many small branches which cannot readily be identified or sutured. Transplanted muscles possess from the outset enough tone to counteract deformity, and in many cases they become educated sufficiently to allow voluntary control over the joints involved.

Another form of plastic operation which may occasionally be adopted with advantage is tendon fixation, which consists in using the tendons of paralysed muscles as additional ligaments by attaching them to the bones above the joint and so preventing deformity. Arthrodesis at the shoulder or elbow may also render valuable a hand which would otherwise be useless from the flail-like condition of one or both of these joints.

Compression of Nerves.

Reference has already been made to the various forms of lesion which may produce compression of nerve trunks, such as cicatrices, callus, aneurysms and, rarely, impacted foreign bodies. In these cases symptoms often come on at some considerable time after the injury, and tend to be progressive; but it must not be forgotten that very severe nerve symptoms are often overlooked in the early stages of a wound, and that symptoms which appear to be of late origin may really have been present from the beginning. The general symptoms of nerve compression closely resemble those produced by division, but muscular hypotonia is as a rule less well defined, the reaction of degeneration is less complete, and trophic changes in the skin and bone apparently do not occur. Anæsthesia is less prominent than after division, and according to Core and Stopford it would appear that in compression protopathic sensation may at times be lost over a wider area than epicritic sensation.

The affected nerve when exposed by operation may be flattened out and ribbon-like, especially if the compressing agent is an aneurysm; it may present a very sharply defined stricture, due to a cicatricial band; it may be not only compressed but dragged out of position; it may be overlaid by or enveloped in a mass of cicatricial tissue, or, especially in the case of the musculo-spiral, by a mass of callus. In the majority of cases it is pale, thin and fibrous-looking, more rarely red and inflamed, or swollen from neuritis. Occasionally it is oedematous above and below the seat of compression, which then looks sharper than it really is.

Practically all such cases require operation, which consists first in the removal of the compressing agent, with the minimum of handling and of damage to the nerve, and, secondly, in replacing the latter in a more favourable bed. In addition to the liberation of the nerve, capsulectomy, or the removal of the outer covering, which may constitute a slight neuroma, is strongly urged by some surgeons; but a removable capsule apart from the general cicatrix is seldom found. When the nerve trunk has been fully laid bare it will be necessary to consider whether or not it has been totally destroyed. If the pre-operation syndrome indicated a complete loss of continuity, and if the nerve is obviously much thinned and fibrous-looking, mere decompression or neurolysis will probably not suffice, and it will be necessary to resect and suture the nerve on the grounds stated by Tinel, that "a good resection is far

better than a bad liberation"; but it is not often that this extreme course has to be adopted. Too much stress cannot be laid upon the importance of removing all surrounding cicatricial tissue, as otherwise compression will shortly recur. In these cases it is probably well to protect the nerve by placing it in a new bed, surrounding it with fat, or if there be an exposed surface of bony callus, covering over the latter with fascia or cargile membrane, to serve as a periosteum.

The results of operations for compression of nerves appear in most cases to be better than those undertaken for resection, although Kennedy's investigation of cases of very old date indicates that there is but little difference in this respect.

Irritative Lesions of Nerves.

Irritative lesions of nerves are as a rule associated with partial section, although they may also occur after complete division and even after amputation. The essential cause is probably, in most if not in all cases, the septic infection of a nerve trunk, giving rise either to local inflammation, as in painful end bulbs, or possibly to spreading neuritis; but the whole subject of ascending neuritis is still very imperfectly worked out.

In lesions of this type, the co-existence of inflammatory changes with partial or complete section gives rise to very complicated symptoms, which differ widely from those of both interruption and compression. The most striking results are that paralysis is partial only, and may be entirely absent; muscular atrophy is little marked; the reaction of degeneration is ill-defined; idio-muscular contraction is usually prominent; hypotonia is often absent or may be replaced by spasm. The sensory symptoms are more obvious than are those of movement. Pain is as a rule severe, of burning, pricking, or tearing character; it usually appears a few days after the injury, tends to increase steadily, and to be aggravated by all movements, contacts, or changes of temperature. The skin is as a rule hypoæsthetic, but anæsthesia is seldom complete, and all forms of stimuli react as pain. Trophic disturbances are well marked; the skin may be dry and desquamating, or is more often covered with a profuse and possibly foetid perspiration. Changes of nails and hair are more marked than in mere nerve section. Occasionally muscles tend to become infiltrated with fibrous tissue followed by cicatricial contraction, producing serious deformities, especially in the hand. Joints and tendon sheaths are inflamed and tend to form

adhesions. Associated with the local symptoms there is often much secondary mental disturbance and depression.

Tinel and others have divided these irritative lesions into various groups, such as the "simple neuritic type" and the "attenuated neuritic type"; but the distinction between these two mainly consists in that, in the first, sensory symptoms, including pain and hyper-æsthesia, are more marked; while in the second there is a stronger tendency to fibrosis, muscular contractures and deformities. The prognosis of these cases is by no means altogether bad as regards the ultimate disappearance of the neuralgic symptoms, although crippling from deformity is often severe and permanent.

A more serious type of irritative lesion is the causalgia of Weir Mitchell, which is highly characteristic of gunshot wounds of nerves. Described originally as met with in the wounded of the American Civil War, its very existence had largely passed out of sight among clinicians until the war of 1914-18. The cases are all closely similar. A few days or even a week or more after the wound, intense burning pain commences in the palm or sole of the injured limb. Of paroxysmal character, this pain is aggravated by the slightest movement or contact, or even by stimulation of distant parts and by mental shocks and surprises. In its intensity, its paroxysms, its tendency to be evoked by light rather than by firm contacts, its intractability to all ordinary treatment, and its disastrous effect upon the mental condition, it closely resembles the pain of trigeminal neuralgia. With it there are usually associated marked trophic changes, which may extend well beyond the periphery of the injured nerve. Cutaneous dryness is usually well defined, and the patient himself constantly seeks relief by moistening the surface; redness is not uncommon and local rise of temperature may even simulate suppuration. After a long period the pain of causalgia appears gradually to diminish and finally to disappear, but some cases which dated from 1914 were still under observation in 1921. The condition is liable to leave much muscular fibrosis or to produce marked local anæmia or gangrene. Actual paralysis is rare, although it may be present in the highly complicated lesions of the brachial plexus.

Pathologically, causalgia is associated with partial section of a nerve, and generally with intra-neural hæmorrhages and sclerosis, its marked incidence in military surgery being no doubt due to the frequency of incomplete nerve section associated with extensive bruising or sepsis. In several cases examined

by Stopford there was discovered extensive endarteritis in the affected area, and however much this may be connected with the nerve lesion it is by no means improbable that such endarteritis plays a considerable part in the determination of symptoms and results.

Causalgia is particularly marked in injuries of the median nerve and internal popliteal division of the sciatic; and much stress has been laid upon the fact that these nerves contain well-marked accompanying arteries. It has been suggested that the changes are in part due to injuries of the vaso-motor tracts, and on this basis is founded the treatment of Leriche.

In connection with the treatment of irritative lesions it is essential to realise the nature of the pathological condition. The trouble may be extra-neural (cicatrices, foreign bodies, fragments of bone and aneurysms), or intra-neural, in which case it is probably a form of neuritis, with or without hæmorrhage. Such internal and external forms of irritation may however be associated together, as when external pressure is followed by internal neuritis; and in all doubtful cases external sources of pressure should be sought for and, if found, removed at the earliest possible moment.

External irritation having been removed, attention will be turned to the relief of pain. Apart from ordinary methods of treatment by drugs, galvanism has generally been found most soothing. The negative pole is placed on the affected nerve above the lesion, and the positive pole on the hand or foot or in a basin of saline solution into which the limb is dipped. A current of some 50 milliamperes is then allowed to pass for about a quarter of an hour, or a current of from 3 to 5 milliamperes can be continued for several hours.

In true causalgia such measures will rarely be effective, and even resection of the injured area of the nerve may fail to give relief. In very severe cases, division of the sensory roots in the spinal cord (rhizotomy) has been practised but has also occasionally failed to relieve the pain. Buzzard and Sicard, following the analogy of alcohol injection in trigeminal neuralgia, have advocated an injection of alcohol into the affected nerve above the lesion. The trunk having been exposed, a fine needle is thrust into its sheath about 3 cm. or 4 cm. above the injury, and 1 or 2 cubic cm. of 60 per cent. alcohol are injected. That the pain can thus be greatly relieved is unquestionable, but it is yet too early to say whether it presents the same tendency to return after many months as does trigeminal neuralgia similarly treated. Sicard has however recorded

cases of freedom from pain for nearly three years, and in view of the tendency of causalgia to ultimate recovery alcohol injection probably gives a sufficient period of relief. Joyce states that he has found the method to fail where subsequent resection has been successful, and also records cases in which it has produced paralysis. Sicard admits that motor troubles may ensue after the injection, but claims that these pass off in from six to ten months.

Finally, on the theory that causalgia is due to the injury of vaso-motor nerves, Leriche advocates removal of the sheath of the main artery of the limb, in order to divide such fibres as lie with the vessel. Good results have been claimed for this operation, but its anatomical basis is doubtful, as the vaso-motor nerves do not run a continuous course in the sheath of the vessel, but join the latter from point to point throughout its course, and they are therefore not cut off at their source by the operation of Leriche.

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CHAPTER VI.

INJURIES TO THE BLOOD-VESSELS.

THE following account of the experiences of surgeons in connection with injuries of the blood-vessels during the war is based on two sets of notes, Series I being notes of 668 cases under the charge of various surgeons at home and overseas, and Series II of 523 cases under the charge of surgeons working in the hospitals on the lines of communication in France. No very notable discrepancies are met with, so that the numbers of the two series are often combined for statistical purposes. Such discrepancies as occur depend mainly upon the fact that the notes of the cases of Series II were made under the direction of one surgeon, while those of Series I are the work of numerous individuals.

It may be said, once for all, that only modified reliance can be placed on any of the deductions drawn from the numbers furnished.

Topographical Distribution of the Injuries.

TABLE I.

Artery.	Hospital Series.	Casualty Clearing Station Series.
Aorta	5	—
Carotid	128	5
Subclavian	45	2
Vertebral	3	2
Axillary	108	15
Brachial	200	39
Forearm	59	26
Common iliac	1	—
External	4	2
Internal	1	—
Femoral	366	51
Popliteal	144	31
Anterior tibial	26	16
Posterior tibial	97	58
Peroneal	4	—
Total	1,191	247

The two lists of vascular lesions in Table I probably give a fair average idea of the incidence of injuries to individual vessels. The first is compiled from the two series of cases,

the second was drawn up by Captain Hey, and records the ligatures of arteries performed at a casualty clearing station during the first battle of the Somme. The visceral arteries are not dealt with in either list. Hey's list gives a good idea of the number of such injuries in a great modern battle. It is much to be regretted that no information is available as to the ultimate fate of the patients operated upon.

These figures support the obvious facts that the length and calibre of the vessel and its comparative accessibility to violence from without are the main factors which regulate the distribution of lesions that come under the care of the surgeon.

The Nature of Gunshot Injuries to the Blood-vessels.

Localized contusions and non-penetrating lacerations are a somewhat special form of injury to the vessels, more frequently met with in military than in civil practice. The fact that such injuries may be followed by early spontaneous thrombosis and obliteration of the lumen of the vessel leads to frequent want of prompt recognition and record of the lesion. Some idea of this fact may be gathered from an examination of the numbers furnished in the two series of cases. In the allocation of cases to Series I little attention was devoted to this point; in Series II every case was specially considered from this aspect, and the following results are obtained:—

TABLE II.

Artery.				Contusion.	Wound.	Total.
Carotid—						
Series I	..	..	..	2	41	43
„ II	..	..	..	19	66	85
Subclavian—						
Series I	..	..	..	—	17	17
„ II	..	..	..	2	26	28
Axillary—						
Series I	..	..	..	2	52	54
„ II	..	..	..	10	44	54
Femoral—						
Series I	..	..	..	1	195	196
„ II	..	..	..	20	150	170
Popliteal—						
Series I	..	..	..	1	58	59
„ II	..	..	..	7	78	85
Totals				64	727	791

The leading characteristic of gunshot contusions is their tendency to be much more extensive than simple ocular inspection suggests. A severely contused vessel may appear little or not at all damaged as it lies exposed in an open wound, although the fallacy of this opinion may often be at once exposed by the discovery of a thrombus occupying the lumen.

In the least serious grades of contusion, such as are seen in Figs. 1, 2, and 3, a localized area of ecchymosis may be visible on the external aspect of the artery while, within, the intima is fissured and the fissure clothed by clot.



Fig. 1.



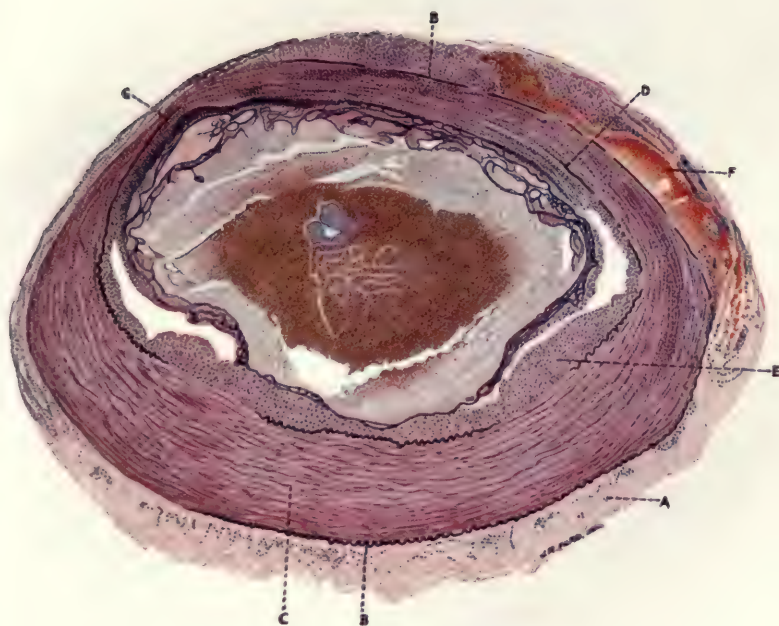
Fig. 2.

Contusion of right common iliac artery, external and internal surfaces.
Linear rupture of the intima and minute perforation.

A more serious grade is seen in section in Plate III. It will be noted that in the lower part of the section the adventitia is normal, while in the upper contused area it is thinned and is the seat of interstitial blood extravasation and leucocytic infiltration. The elastic laminae opposite the contused area are stretched, straightened out, and fissured; the muscular coat is thinned out almost to obliteration; the sub-endothelial layer is irregularly thickened; the endothelium is gone; and the lumen of the vessel is occupied by clot of gradual formation.

Plate IV illustrates the most serious grade, in which extensive laceration of tissue accompanies the contusion.

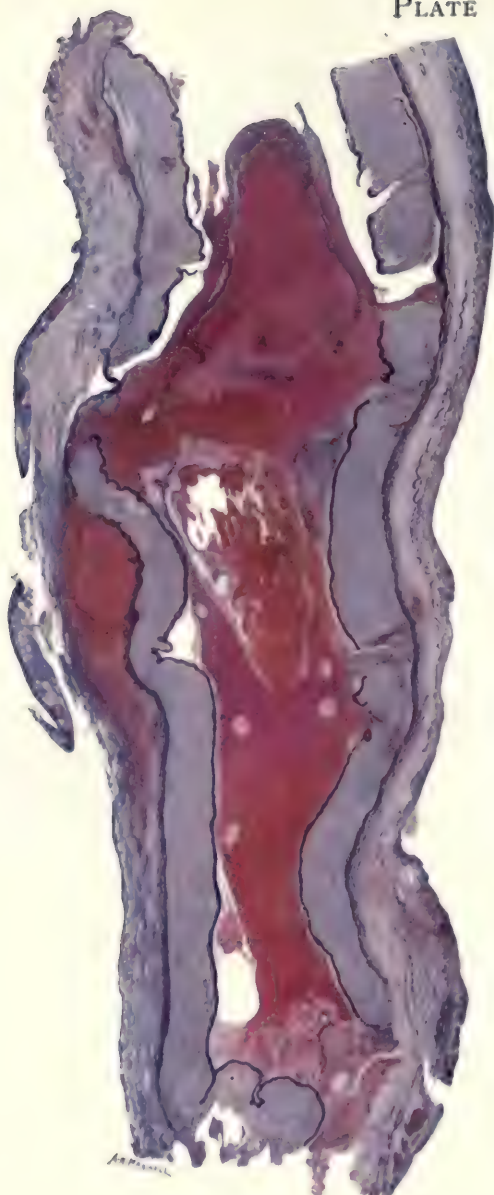
The practical significance of this form of injury is great, as may be gathered from the following facts.



Slightly oblique transverse section across a contused artery. A. Adventitia ; B. External elastic lamina ; C. Media ; D. Internal elastic lamina, destroyed in upper part of figure ; E. Thickened sub-endothelial layer ; F. Hæmorrhage into adventitia ; G. Extreme thinning of media at point of maximal injury.



(a)



(b)

- (a) Thrombosed segment removed from superficial femoral artery. The upper of the two dark spots corresponds with the point from which secondary hæmorrhage took place. The lower of the two dark spots is the outward manifestation of the extensive hæmorrhage within the destroyed or necrosed adventitia, a portion of which is shown displaced in the figure. In several other sections it was found to be continuous with the tissue above and below by a thin membrane covering the extravasated blood.
- (b) Longitudinal section through the contused vessel shown in (a). Multiple ruptures of the intima and media. Extravasation into the adventitia. At one point the adventitia has necrosed and given way, and allowed the occurrence of secondary hæmorrhage.

In the slightest grades clot forms on the site of the ruptured intima, and the thrombus may be the source of emboli, although only a lateral thrombus not obstructing the lumen is present.

Although the lesion may heal spontaneously a weak point is left in the wall of the vessel, capable of distension at a later date (Fig. 4).

In infected wounds the presence of a contused or partly lacerated vessel is the most frequent source of secondary hæmorrhage.

In infected or non-infected wounds, if contusion has been sufficient to destroy the vitality of the tissues delayed development of traumatic aneurysm may result.

Thrombosis may result in permanent lowering of the nutrition of the parts supplied, in muscular ischæmia or in anæmic gangrene.

All these sequences are illustrated below in the description of injuries to the individual vessels. The permanent effect on the part supplied is strongly exemplified in the case of the axillary artery, where associated nerve lesions are so common.

Gunshot injuries to the blood-vessels differ in no essential particular from those of the soft parts in general, the most important feature being the association of contusion, which may render closure by suture difficult or unsatisfactory.

The details most likely to affect the procedure of the surgeon consist in the amount and degree of tissue destruction and in the direction of the wound in relation to the long axis of the vessel.

Wounds of the Arteries.

In dealing with wounded arteries certain points must always be kept in mind: (1) That the associated contusion may have lowered the vitality of the margins of the wound to a degree



Fig. 3.—Contusion of abdominal aorta; fissuring of intima with minimal deposition of clot.

which ocular inspection may be incapable of determining, (2) that such injury may be extensive within the lumen of the vessel, and (3) that the intima may not only have suffered by contusion but that, as a result of stretching by displacement, the intima may be fissured at a considerable distance from the wound itself (Fig. 5).

In the quite recent state, some wounds appear remarkably clean cut. This is often so when the vessel has suffered complete severance, and it is obvious that when the lesion has been produced by a sharp fragment of metal the wound may be of an incised nature.



Fig. 4.

Lateral suture of superficial femoral artery. Small aneurysmal dilatation. Ligature of femoral vein.

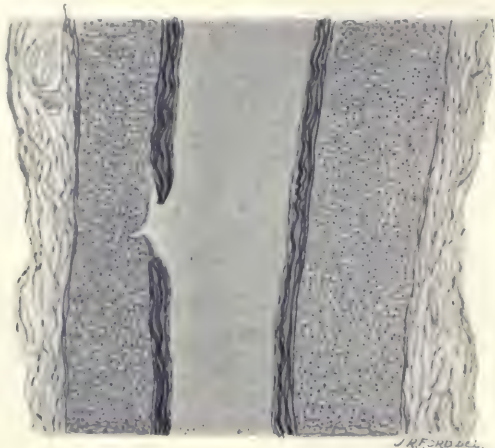


Fig. 5.

Section of radial artery, showing a rupture of the intima involving the muscularis, discovered 1 in. from a small contused perforating wound.

Generally the margins are somewhat irregular and tattered; in some instances definite small flaps of the wall of the vessel lie in the opening. The openings tend rapidly to assume a more or less regular outline of rounded or oval form, the intima and adventitia meeting as a result of rapid endothelial proliferation. Well marked rounded openings are therefore commonly met with when hæmatomata of several days' standing are laid open, a fortunate condition since, if the case be one suitable for suture, the approximation of endothelial surfaces is rendered easy.

It is not uncommon for more than one wound, or even two arterio-venous communications to be met with in the course of one and the same vessel.

For convenience of description the wounds have been classified as: (a) lateral; (b) traversing perforations; (c) complete severances.

Lateral Wounds.—These may be transverse, oblique or longitudinal as considered in relation to the long axis of the vessel. The least important are the minute perforations produced by small fragments of metal. In such the wound may heal spontaneously, although it is remarkable how small an opening occasionally remains patent. Small lateral wounds of the transverse variety do not materially differ in appearance from the perforations of traversing lesions, but the characteristics of the apertures of entry and exit are not maintained. The most satisfactory lesions from the point of view of the surgeon are limited longitudinal wounds, as they may often be repaired by suture without material diminution of the calibre of the vessel (Fig. 4).

Transverse wounds gape widely when more than a quarter of the calibre of the vessel is involved, and when more than half of the calibre is involved a change in the axis of the vessel takes place, as pointed out by Sencert, the remaining strand of the wall forming an obtuse angle, the apex of which is salient to the lumen. This change of axis favours hæmorrhage into the tissues by diverting the direction of the course of the blood stream, while the advantages of complete retraction of the ends of the vessel are lost in consequence of the check provided by the remaining strand of the arterial wall.

Perforations.—These are the injuries in which both aspects of the vessel are wounded by a traversing missile. When caused by bullets the openings may be small, but the apertures of entry and exit possess the same characteristics as those seen on the surface of the body. It is remarkable, and an excellent illustration of the power of lateral displacement possessed by a rapidly travelling bullet, that vessels of much smaller calibre than the bullet itself may exhibit injuries of this class.

Fig. 6 is a good example of the type of perforation seen in arteries and veins when caused by fragments of shells. The comparatively neat slit in the vein illustrates the difference commonly seen between wounds of the veins and arteries respectively.

Complete Severances.—Severance of continuity is not uncommon, especially in vessels incapable of much displacement, or struck when in a state of comparative tension. When the missile follows a course parallel to that of the vessel, long segments of the artery may be carried away. Completely

severed vessels may not bleed at all; they were frequently discovered in wounds when not expected, even in arteries the size of the axillary or femoral. Many instances of reported complete severance were really extensive transverse wounds, in which the remaining strip of arterial wall became incorporated in the wall of a traumatic aneurysm, or was difficult to differentiate in a mass of tissue heavily infiltrated with blood.



Fig. 6.—Perforating wound of femoral artery and vein. Adhesion of the opposing sides of the vessels has established a direct arterio-venous communication. Opening in artery with irregular shredded margins, that in vein more incised in character. Shell injury.

Wounds of the Veins.

These differ from wounds of the arteries mainly as a result of the comparative tenuity of the venous walls, and the small amount of muscular tissue included. Fig. 7 is an example of a simple wound. When lacerated or severed by irregular masses of metal, the wall of the vein may be much frayed and tattered.

Healing of Wounded Vessels.

Completely divided vessels may heal spontaneously in exactly the same manner as those closed by ligature.

Perforations and small lateral wounds, even of great vessels such as the aorta, may also heal spontaneously, the initial opening being sealed by clot, and the inner aspect of this protected from the force of the blood stream by the formation of a provisional thrombus.

When the openings gape they become regular in outline, and intima and adventitia become continuous around the

aperture, so that an arterial fistula commonly communicating with a traumatic aneurysm is formed.

Spontaneous closure may be facilitated by the lateral adhesion of neighbouring structures, especially veins or nerve trunks taking a parallel course.

Severe contusion or incomplete laceration of the walls of the vessels is followed by spontaneous thrombosis, and in

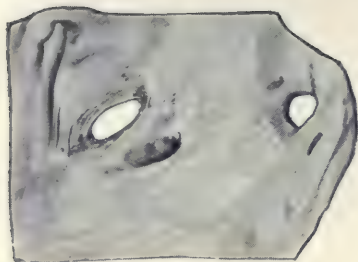


Fig. 7.—Recent perforation of common iliac vein.

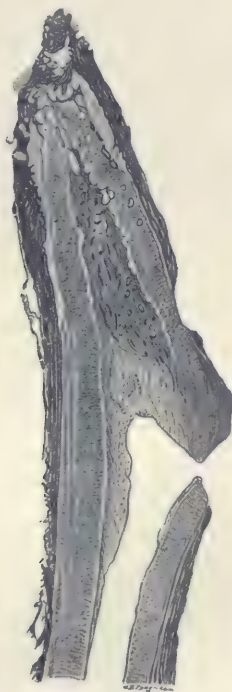


Fig. 8. Spontaneous healing of axillary artery, and occlusion of lumen.

such circumstances the lumen is usually permanently occluded. A sharp distinction must be drawn between such thrombi and those which are attached to a small localized injury. The latter form no intimate connection with the wall of the vessel except at the spot actually damaged; they contract, allow the resumption of the blood-current, and may be completely absorbed. Fig. 8 illustrates the spontaneous closure of a severely contused and lacerated vessel.

Temporary Control of Hæmorrhage from Wounded Arteries.

Mechanical control by pressure from an adjacent piece of metal is common, and accounts for many cases of recurring primary hæmorrhage when the missile is removed, and for secondary hæmorrhage if the wound should become infected.



Fig. 9. Skiagram showing the bones of the thigh and leg opposite the popliteal space. An impacted bullet is seen lying transversely in the popliteal space. The point of the bullet, after traversing the popliteal vein, is lodged in the popliteal artery without penetrating the anterior wall. Removal of the bullet some days after its entrance was followed by free hæmorrhage, necessitating ligation of both vessels.

Fig. 9 illustrates control by a bullet which, after perforating the vessel, remained in position; other instances of this accident to the same artery have been recorded by Sheen and other observers.

Fig. 10 illustrates permanent obliteration of an artery by the healing in of a fragment of metal which probably never

actually entered the lumen of the vessel. Small fragments entering a vessel sometimes find a permanent location on the opposite wall.

Complete obstruction by missiles which, after entering the heart or a large vessel, move onwards in the circulation and form metallic emboli at the classical spots in the circulation is not rare. This accident is illustrated in Fig. 11. The embolus in such cases becomes covered with clot, and the typical signs of local obstruction develop. Many cases of successful removal of such foreign bodies have been recorded.



Fig. 10.—Impacted foreign body in the axillary artery.

Effects of Wounds of the Blood-Vessels.

Little new light has been thrown on the subject of primary hæmorrhage, except perhaps in a juster appreciation of the relation of primary hæmorrhage to the occurrence of local anæmic gangrene, and of the value of blood transfusion in its treatment. Once again, the experience of a vast and prolonged campaign has not provided any more exact estimate of the mortality to be ascribed to this cause alone.

Secondary hæmorrhage was perhaps more closely studied than had been possible in times of peace. The net result was to confirm the influence which infection exerts on the occurrence of secondary hæmorrhage, and also the fact that incomplete lesions, such as contusion or laceration not involving the entire thickness of the walls of the vessels, were responsible for a large proportion of the cases. Pressure necrosis, consequent on the prolonged retention of drainage tubes, was possibly assigned a greater importance than facts warranted. Improvement in the technical treatment of wounds in the later stages of the campaign was accompanied by a notable decrease in the mortality from this cause. The academic discussion which took place regarding the relative influence of the saline and antiseptic methods of treatment respectively upon the occurrence of this accident supplied little useful information.

Treatment of Hæmorrhage.

The rules most generally followed in the treatment of primary hæmorrhage may be set down as follows :—

(1) Bleeding vessels in an open wound are always to be ligatured at the earliest possible moment.

(2) When injured vessels, and especially those of large calibre, are visible in open wounds they are to be ligatured whether bleeding or not.

(3) When a large vessel is exposed in an open wound and has obviously suffered contusion and is thrombosed, the vessel should be ligatured above and below the thrombosed segment, and the latter excised. This procedure obviates the subsequent danger of secondary hæmorrhage, which is incalculable from external inspection of the vessel alone, as has been pointed out in connection with contusion of the arteries.

(4) When evidence exists that a large vessel has been wounded in the course of a track traversing the body or limbs, unless the conditions are favourable it is not advisable to interfere primarily if no signs of progressing hæmorrhage are forthcoming, or if there are no indications that the vitality of a distal portion of the limb is becoming endangered. In all such cases, although an arterial hæmatoma and subsequently a false traumatic aneurysm may result, yet the later treatment of either of these conditions in favourable circumstances for operation is to be preferred to the risks



Fig 11.—Fragment of shell occluding left external iliac artery.

attendant on a primary operation in the front line.

It is obvious that the fourth rule is one open to variations under favourable conditions; but even then, if a large primary hæmorrhage has taken place, an expectant attitude

is better for both the immediate and remote nutrition of the parts supplied by the wounded vessel.

In the treatment of secondary hæmorrhage the administration of various hæmostatic drugs proved of little utility.

Direct ligation of the bleeding spot proved the safest and most effective method, and proximal ligation, except in the one case of the internal iliac artery, was again shown to be unreliable or dangerous. Forcible pressure and plugging both proved useful where direct ligation was impracticable, and formed the last resorts of surgery.

In the general treatment of the consequences of hæmorrhage, advance was undoubtedly made in the more frequent adoption of methods calculated to increase the total volume of fluid in the blood-vessels.

In the early stages of the war, this was attempted by infusing normal saline solution into the venous circulation, by infiltration of the subcutaneous tissue with similar fluid, by rectal injections, and above all by administering copious draughts of fluid by the mouth when possible.

It was not until a later period that replacement of whole blood became a generally recognized method of treatment. For the introduction of transfusion as a routine procedure credit must be given to the efforts of surgeons from Canada and the United States. They had been actively aroused by the work of Carrel and Crile, and were familiar with the method of Kimpton, which exercised so great an influence on the practical adoption of transfusion for the replacement of blood lost by hæmorrhage.*

The matter may be shortly summed up as follows :—

(1) In sudden and abundant primary hæmorrhage, immediate transfusion is indicated.

(2) In less severe cases, Bayliss's gum-arabic solution should be tried, and followed by transfusion of blood if no permanent effect has been produced.

(3) In milder cases, an attempt to restore the blood volume may be made by the administration of large amounts of fluid by mouth or by rectum. If necessary these attempts may be followed by the more active procedures.

(4) In case of secondary hæmorrhage the hæmoglobin content is most likely already depressed to the critical point. Consequently, even a moderate hæmorrhage will reduce it to a point incompatible with an efficient natural recovery ; hence

* For fuller details of this form of treatment see "Surgery of the War," Vol. I, Chapter V.

immediate transfusion of blood is the safest course. The beneficial effect to be hoped for from transfusion is greatly lessened in patients who are the subjects of general infection.

Interference with the Vitality of the Parts supplied by the Wounded Vessel.

Short of the death of the patient from hæmorrhage, deficiency of the amount of blood furnished by a wounded vessel to the peripheral circulation leads to varying degrees of loss of volume of the part affected, to lowered nutrition of the parts supplied, or to actual gangrene.

These defects may depend on local pressure exerted upon the vessels in the neighbourhood of the wounded spot by extravasated blood which coagulates, on sudden obliteration of the lumen of the vessel by rapid spontaneous thrombosis, on the act of the surgeon who applies a ligature, or on secondary narrowing, and perhaps thrombosis, occurring during the process of cicatrization.

It must also be borne in mind that signs suggesting complete obliteration of the lumen occasionally follow contusion of a vessel when no actual obstruction exists. The condition has been designated "arterial stupor," and Veau ascribes it to a state of general vasomotor constriction of the vessels of the part supplied.

It is an undoubted fact that minor wounds of the large arteries may heal spontaneously, and the parts supplied by the vessel suffer no material injury. In the immense majority of cases, however, either some narrowing of the lumen develops, or the vessel is completely obstructed by an organizing thrombus, or by the act of the surgeon. Probably the most fortunate of the severe cases are those in which one of the forms of traumatic aneurysm develops, as time is then given for some readjustment of the peripheral circulation before surgical intervention is necessary.

The structures in the limbs which suffer most severely from the primary anæmia are the muscles. These retain their normal outline and increase in firmness in consequence of the assumption of a fictitious tone, due to exudation within their sheaths and rapid nutritional changes, which it has been suggested resemble those of an early condition of rigor mortis. Muscles thus affected may to a great extent recover, but in some instances a progressive change continues until a state corresponding with the muscular ischæmia of Von Volkman is reached.

Rapid wasting of the limbs after a wound of a vessel is rare except in association with general systemic infection from the wound of the surrounding soft parts.

Should a vessel suffer actual obliteration, however good the ultimate functional result may be, a certain loss of volume of the limb is constant, the peripheral blood pressure in the limb is permanently lowered from 10-20 mm. of mercury, and the peripheral pulse never regains its normal strength and volume.

Anæmic Gangrene.

The 992 injuries to the large arteries included in Series I and II show that massive gangrene of varying extent occurred in no less than 178 instances. The numbers are as follows, cerebral complications being regarded in the table as comparable with gangrene of the limbs :—

TABLE III.

Artery.	No.	Gangrene.	Percentage Occurrence.
Carotid	128	38	29·6
Subclavian	45	4	8·8
Axillary	108	3	2·7
Brachial	200	8	4·0
Common iliac	1	1	100·0
Femoral	366	74	20·2
Popliteal	144	50	34·7
Totals	992	178	17·9

An average incidence of gangrene amounting to 17·9 per cent. appears high in comparison with the 6-12 per cent. with which the arteries of the limbs when ligatured are credited. It must be recognized, however, that many of these arterial injuries were complicated by large—often infected—lacerated wounds, by injuries to the large nerves, or by fracture of the bones, not to enumerate certain other troubles to be mentioned below. Here, as in so many other instances, gunshot injuries require to be regarded from an individual aspect.

It should also be emphasized that in speaking of massive gangrene it is not intended to imply that whole limbs or even great parts of them were lost ; in many cases only digits or fractions of digits perished. Some further details on this point will be met with under injuries to individual vessels.

It will be observed that the proportion is high in the case of the carotid arteries, either as a result of wound, contusion or ligature.

The upper extremity arteries (subclavian, axillary and brachial) taken together give 353 cases, in 15 of which gangrene occurred. It did not occur in any of the injuries to the arteries of the forearm.

Special mention should be made of the four instances in which gangrene followed injuries to the subclavian artery, because in three of these gangrene of the hand and forearm was due to embolism and obstruction of the brachial artery at the point of bifurcation. It happens that the arrest of an embolus at this spot is particularly easy to detect, while in the lower extremity this is not the case if an embolus should lodge at the bifurcation of the popliteal artery. Hence it may be assumed that embolism is a more frequent accident than is always possible to demonstrate clinically.

In the lower extremity there are 510 injuries to the femoral and popliteal arteries with 124 cases of gangrene—24·3 per cent. In no instance included did gangrene follow an injury to the external iliac artery, although the accident once followed a wound of the common iliac. The tibial vessels are not included, because gangrene is unlikely to follow injury to one of them, while on the other hand gangrene following injury to one or both vessels complicated by anaërobic infection of the wound was extremely frequent, but has no special bearing on the question.

The popliteal artery heads the list in numbers, as beyond it the area of gangrene was more extensive than was the case with the femoral vessels. In the latter the loss of digits, part of the foot, or the whole of the foot was the common extent, and amputations at the ankle or through the leg were the usual consequence. In popliteal injuries it was rare that amputation through the thigh could be avoided. These results support the general rule that the nearer the injury to the trunk the better the result is likely to be.

The following conditions, all common in military practice, are of importance as favouring the occurrence of gangrene:—

(1) Great decrease in the total volume of blood due to hæmorrhage.

(2) Exposure to cold and exhaustion; in several cases gangrene of the injured limb was associated with "trench foot or hand" of the uninjured limb.

(3) Prolonged retention of a tourniquet, especially dangerous in the case of the popliteal artery

(4) Infection of the wound, general systemic infection, and secondary hæmorrhage.

(5) Associated injury to nerves, especially the median in the upper extremity and the internal popliteal in the lower.

(6) The extent and severity of associated injury to bones or soft parts.

Further remarks on the subject of gangrene will be found in connection with treatment and with injuries to the individual vessels.

Traumatic Aneurysms.

Among 1,004 injuries to the great arterial trunks, some form of aneurysm occurred in 545, or 54·4 per cent.

TABLE IV.

Artery.	Number.	Arterial.	Arterio-venous.	Total.
Aorta	5	3	—	3
Innominate	2	—	2	2
Carotid	128	26	60	86
Subclavian	45	17	17	34
Axillary	108	50	28	78
Brachial	200	61	18	84*
Iliac	6	2	2	4
Femoral	366	98	102	200
Popliteal	144	29	25	54
Totals	1,004	286	254	545

* Variety not recorded in 5.

Two defects in this table must be pointed out. No distinction has been drawn by the majority of surgeons between the stage of hæmatoma and aneurysm; neither are the cases of aneurysmal varix separated from those of arterio-venous aneurysm. It must, however, be allowed that no fixed period can be allotted to the hæmatoma stage, and again that the question of the presence or not of a sac in an arterio-venous lesion can often only be determined at the time of operation. Hence, although some attempt is made to separate these conditions in the special sections, it has been thought better to mass them together in the above table.

Observation of a large number of cases during the war has shown that the cavity of a traumatic aneurysm rarely represents the pool of blood which results primarily from the wound of

the vessel. Fig. 12 represents the more common early condition when the implicated vessel is surrounded by structures that afford support and resist extensive extravasation. The extravasated blood coagulates, the wound in the wall of the vessel is closed by clot, and is supported internally by a temporary thrombus. This condition may occasionally end in spontaneous cure. More commonly the supporting internal thrombus—usually not so perfect as in Fig. 12—shrinks, the



Fig. 12.

Wound of the right common carotid artery. The interior of the vessel is occupied by a cylindrical clot starting from the wounded spot and extending peripherally. The contracted thrombus is not of sufficient calibre completely to obstruct the blood-stream. A solid mass of clot is attached to the outside wall. A condition of solidified hæmatoma exists which might be followed (a) by spontaneous healing of the wound of the wall of the artery, or (b) by the delayed development of a false aneurysm.

wound in the wall of the vessel is exposed to the full force of the circulation, and a cavity is gradually hammered out in the centre of the mass of external clot. Concentric layers of fibrin are now deposited on the wall of the new cavity (Fig. 13), and later this becomes covered by an endothelial lining. Meanwhile the original external clot shrinks, becomes differentiated from the surrounding tissues and affords the basis upon which a definite sac of fibrous tissue is developed. Fig. 14 illustrates the formation of such sacs in an intermediate stage.

The mode of formation of the sac in arterio-venous aneurysms is identical with what has been described above, the sac being

developed with one exception (variety 7) in connection with the artery.

At least eight definite varieties are met with in the arrangement of the sac and participating artery and vein. (Fig. 15.)

- (1) A simple arterio-venous anastomosis.
- (2) A sac interposed between the artery and vein.
- (3) A sac at one side of the artery and a direct anastomosis of the artery and vein on the opposed aspect.

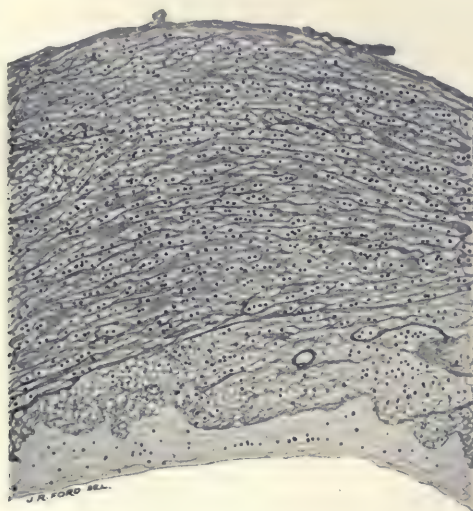


Fig. 13.—A section of the wall of the small aneurysmal sac, magnified to demonstrate its structure ($\frac{2}{3}$ objective). The wall is formed by interlaced concentric laminae of fibrin and within the meshes of the network blood-corpuscles. No fibrous tissue has yet been developed.

(4) A sac springing from the free side of the artery, and a second sac interposed between the artery and vein.

(5) A sac with which the artery and vein communicate by a common opening.

(6) A sac communicating with the artery and vein by separate openings.

(7) A sac springing from the free side of the artery, and a second from the free side of the vein.

(8) A sac springing from the artery, with which the proximal end of a completely divided vein communicates.

Table IV does not show any material difference in the numbers of arterial as compared with arterio-venous aneurysms, 286-254. It will be noted, however, that the arrangement of certain vessels favours the occurrence of the arterio-venous form. Thus the long, parallel course taken by the common carotid artery and internal jugular vein results in the occurrence of a very large proportion of arterio-venous aneurysms (arterial 26, arterio-venous 60). On the other hand, in spite of

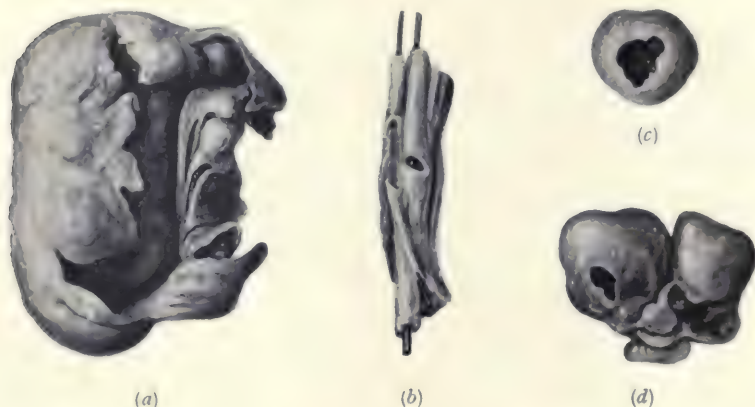


Fig. 14.—Three small false aneurysmal sacs developed in connection with wounds of the posterior tibial artery in their early stage. The largest and most irregular (*a*) has beside it the artery (*b*) showing a small lateral wound and one of the venæ comites also wounded. The patient from whom it was removed had a compound fracture of the leg, the wound accompanying which was badly infected. Pulsation and a purely arterial bruit were not noted until the tenth day. On the fifteenth day secondary hæmorrhage occurred and the limb was amputated. The smallest sac (*c*) is fairly symmetrically globular; the hole by which the wound in the artery communicated with it is well shown, also the tenuous nature of its margins. A magnified section of the wall of this sac is seen in Fig. 13. The third sac (*d*) resembles the two others in character; the small hole communicating with the lumen of the artery is seen. The whole structure is somewhat tripartite in outline, but the two secondary masses contain only a small cavity, and consist mainly of solid clot.

a parallel course of the vessels, the disproportionate calibre of the brachial artery and veins explains the occurrence of only 18 arterio-venous as compared with 61 arterial aneurysms.

In Series I it has been impossible to calculate the proportion of simple aneurysmal varices as compared with arterio-venous aneurysms, but in Series II an attempt has been made to show this.

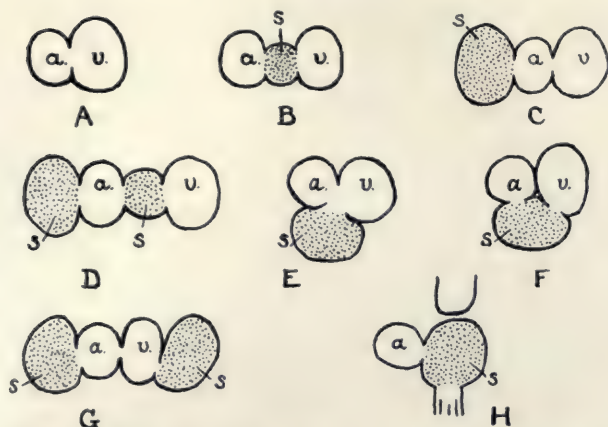


Fig. 15. A, Simple aneurysmal varix. B, Arterio-venous aneurysm, sac interposed. C, Arterial aneurysm combined with aneurysmal varix. D, Arterial and arterio-venous sacs. E, Arterio-venous sac with common opening of communication with artery and vein. F, Arterio-venous sac with separate openings of communication with artery and vein. G, The very rare condition in which an aneurysmal sac is formed in connection with both artery and vein, together with an anastomosis between the two vessels. H, Complete severance of continuity of the vein, the distal segment of which has become occluded. The sac is attached to the side of the artery and to the proximal segment of the vein.

TABLE V.

Artery.	Cases.	Arterial.	Arterio-venous.	Aneurysmal varix.
Carotid	57	10	29	18
Subclavian	24	13	11	—
Axillary	41	24	8	9
Brachial	22	17	1	4
Femoral	87	36	34	17
Popliteal	41	20	17	4
Totals	272	120	100	52

Table V shows aneurysmal varices to be of comparatively common occurrence. The anastomosis is usually immediate, direct primary union takes place, at first dependent on sealing by blood-clot effused between the two vessels. A typical example is seen in Fig. 16, while Fig. 17 depicts the mode of union.

From a practical point of view and also in relationship to military arrangements, considerable differences in the immediate importance of the arterial and arterio-venous forms of traumatic aneurysms exist.

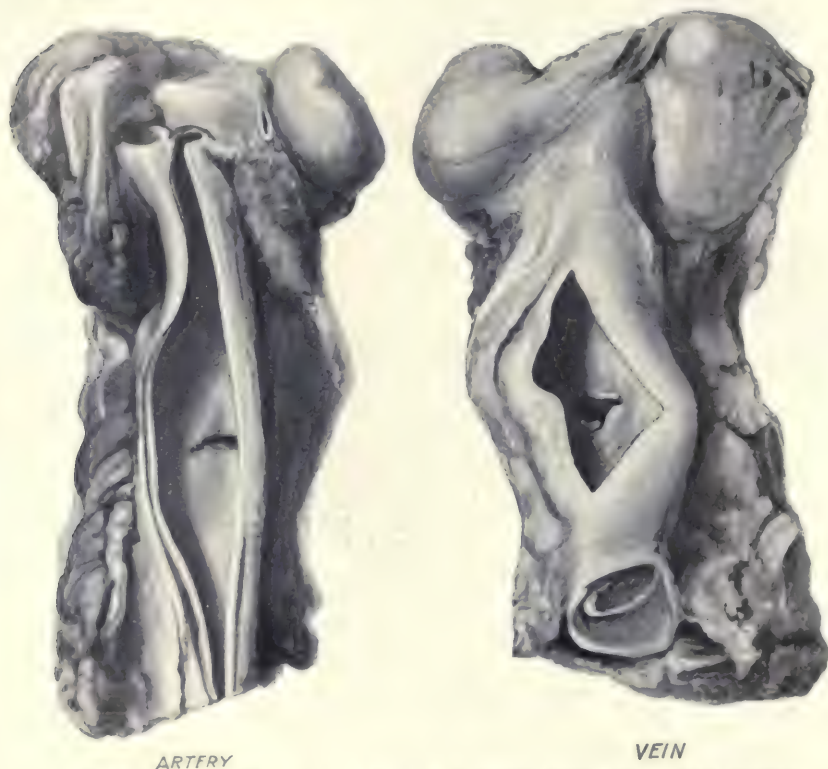


Fig 16.—Aneurysmal varix of the left common carotid artery and internal jugular vein. A simple transverse lateral slit is seen from the interior of the artery and a roughly stellate opening from the interior of the vein. No blood had been extravasated into the vascular cleft, and adhesion between the two vessels was immediate and complete. The typical signs of a carotid aneurysmal varix were present. The patient died on the seventh day from concurrent injuries to the head.

The arterial is the more serious ; it tends to increase in size more rapidly, and it is more liable to accidents in consequence of the greater internal pressure to which its walls are exposed. The danger of accidents is mainly present in the hæmatoma stage, while the boundaries of the sac are still in a state of imperfect development. In this stage, a movement of the surrounding muscles, or extension of a limb, may suffice to

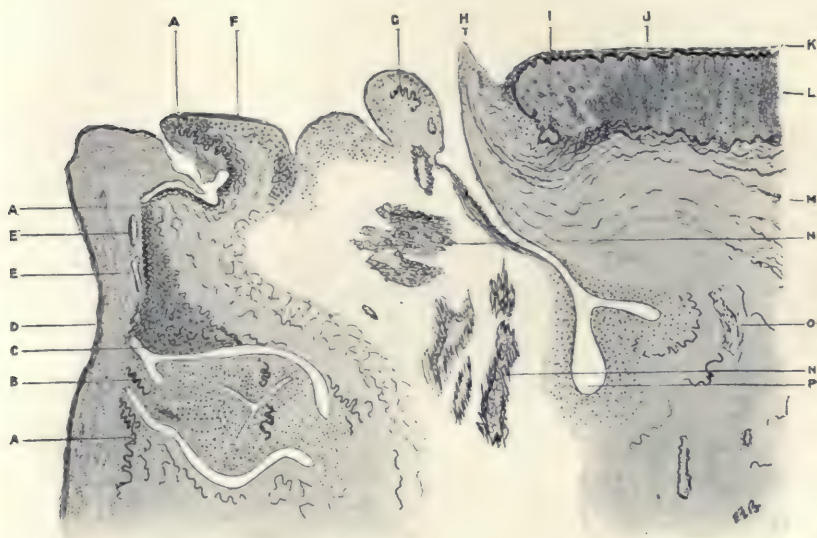


Fig. 17.—Aneurysmal varix of femoral artery and vein. Semi-diagrammatic view of the angle of union of the artery and vein. Union has been effected by means of an intervening portion of displaced tissue derived from the adventitia and muscular coats of the artery, and it contains also a portion of the internal elastic lamina. The displaced tissue is united to the wall of the artery partly by continuity and partly by blood-clot, but to the wall of the vein by blood-clot only.

A, Internal elastic lamina of vein. B, Deep clot in rent in vein continuous with the wound and containing portions of internal elastic lamina. C, Disorganized muscular coat of vein. D, Endothelium covering organized clot adherent to vein wall. E, Spaces lined by endothelium at original level of endothelium of vein. F, Everted wall of vein, muscular coat and adventitia covered with organized clot and lined with endothelium. G, Displaced internal elastic lamina, probably of the artery. H, Everted external elastic lamina and adventitia of artery; this projecting point is the only surface not covered by endothelium; this fact, and the fibrin clot and leucocytes situated between it and the artery, suggest that it may have vibrated in the blood-stream. I, Retracted internal elastic lamina of artery. J, Proliferated endothelium of artery, the proliferation being slight compared with that of the vein. K, Increased thickness of sub-endothelial tissue. L, Muscular coat, disorganized clot only at site of injury and becoming normal at extreme right. The muscle fibres throughout appear somewhat swollen, and there is everywhere a slight infiltration of red blood-corpuscles. M, Adventitia of artery. N, Displaced portions of muscular coat of artery. O, Displaced portions of small nerve. P, Part of track of the missile, lined throughout by endothelium lying either on blood-clot or directly on the walls of the vessel. In the mid-point of the left-hand side of the track, much proliferation of endothelium.

tear the thin margin of the developing sac from the wound in the wall of the artery, and secondary hæmorrhage takes place, resulting in either external bleeding or rapid extension of a hæmatoma. The so-called "bursting of an aneurysm" was no rare event during periods of transport of the patient, or soon after his arrival at a hospital on the lines of communication or at the base. The risk of secondary hæmorrhage was greatly increased in the event of the wound becoming infected. A large number of the early operations was performed as a matter of urgency in such circumstances. Again, as a result of the proneness of arterial aneurysms to extension and rapid increase, signs of pressure either upon the vascular trunks themselves or on neighbouring structures, much more frequently called for early operation than was the case with arterio-venous aneurysms. These points are illustrated in the case of femoral aneurysms in Table VIII, Chap. VIII.

Arterio-venous aneurysms are not only less prone to rapid increase and early accidents, but also tend to localize and diminish in size. This depends on the simple fact that the open vein serves as a safety valve and prevents the full arterial blood pressure ever being exerted on the walls of the sac. The effects of the venous obstruction to which they give rise become important in the later stage of their history.

Accidents in cases of aneurysmal varices are practically unknown in the absence of infection.

As a consequence of their mode of development, the incorporation of important structures in the wall of traumatic aneurysmal sacs is comparatively common, especially in the case of nerves implicated by the same injury. Fig. 18 affords a striking example, and in this instance the sheath of the nerve might have formed the actual sac wall. Examples are quoted later of adventitious sacs formed in a pulmonary cavity, and in the medullary cavity of a fractured humerus, and of calcification of the wall of the sac in connection with a fracture of the femur.

Delay in the development of traumatic aneurysms was very frequently noticed. Many explanations may be given of this circumstance. The first and not uncommon one was that the condition escaped notice, sometimes as a consequence of the patient being the subject of multiple small wounds, or several small wounds and a large and serious one well away from the seat of the vascular injury; or again, in such a vessel as the popliteal, when accompanied by a severe wound of the knee joint on which the surgeon's attention was concentrated.

In support of this explanation, it may be pointed out that aneurysmal varices were often overlooked, in spite of the fact that this condition is an immediate result of the wound and could have been certainly recognized by auscultation.

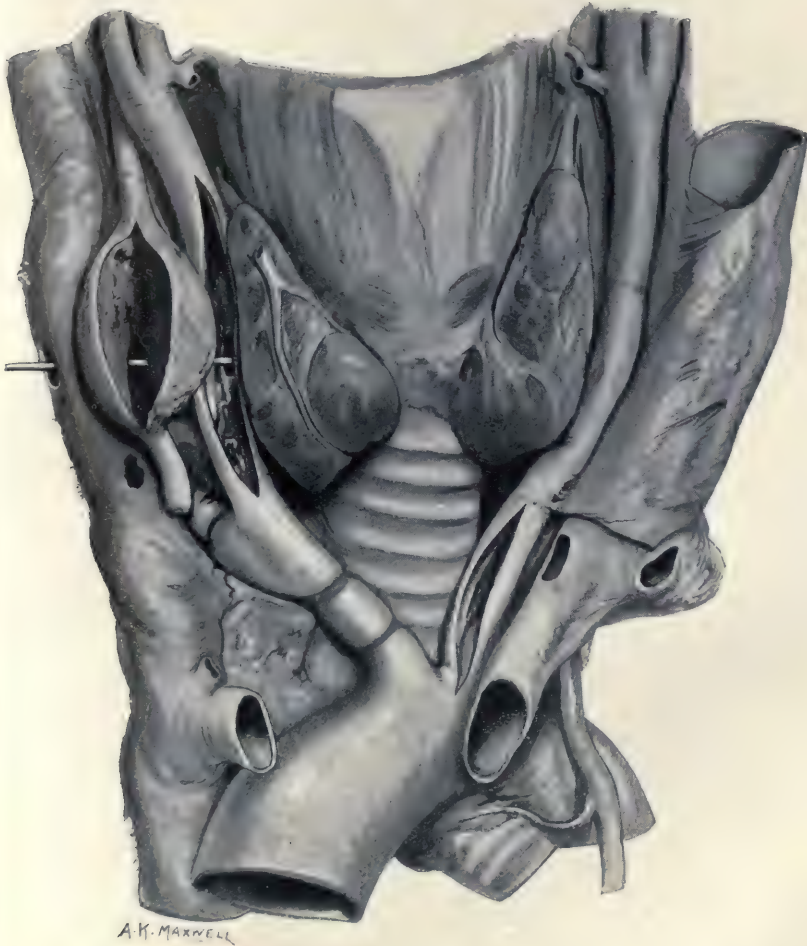


Fig. 18.—Bilateral injury to the carotid arteries. On the right side the missile has traversed the artery, vein, and vagus. The sheath of the vagus is distended by clot, and might eventually have formed the boundary of an aneurysmal sac. On the left side, an arterial aneurysm which formed secondarily was operated upon, and a Tuffier's tube was introduced. It will be observed that a column of connective tissue corresponding in calibre with the tube now connects the two extremities of the severed artery.

In other cases the original wound was closed by the impaction of a metallic fragment, which later loosened; the artery on the proximal side was compressed by a large clotted extravasation of blood; or temporary thrombosis closed the vessel for a time.

In a third series of cases, sloughing of a severely contused portion of the arterial wall took place at about the same time that a secondary hæmorrhage might have occurred. This accident was especially likely in infected wounds.

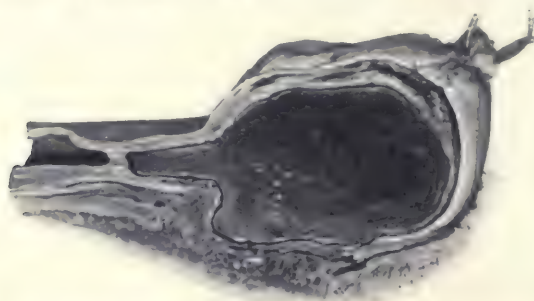


Fig. 19.—Septic aneurysm of the femoral artery, which formed in the floor of an amputation wound. General dilatation of the softened coats of the artery will be observed above the point of ligature. Intramural extravasation of blood has occurred between the different layers of the arterial wall, and at the under surface complete disintegration and necrosis will be observed. The cavity of the sac has become shut off from the lumen of the artery, and is occupied by recent clot.

Lastly, a cicatrized vessel might give way as the result of strain at a late period, or as a minor mischance a partially injured spot became dilated by the force of the blood pressure. These latter dilatations were usually small. (Fig. 4.)

It may be convenient to mention at this point the septic aneurysms which developed not infrequently as a result of inflammation and softening of the stump of large arterial trunks in infected amputations. These were a not infrequent precursor of secondary hæmorrhage; fortunately the bright red pulsating swelling was often noticed in time, promptly dealt with, and secondary hæmorrhage was avoided. (Fig. 19.)

Methods of dealing with Wounds of the Blood-vessels.

Reference has already been made to the immediate treatment of hæmorrhage, but it will be convenient to deal with some of the general questions which arise in dealing with arterial injuries.

Provisional control of the circulation during the performance of operations may be obtained by the tourniquet or by provisional ligature. The use of the elastic tourniquet has been decried, yet it is the only substitute for the direct application of a clamp or provisional ligature to the artery on the proximal side of the wound. In spite of criticism, especially the assertion that it encourages later parenchymatous bleeding, the elastic tourniquet has remained the most commonly employed method, and in the limbs, when it can be applied without encroaching upon the field of operation, its advantages are manifold. It can be put on rapidly, and it controls the entire circulation; for instance, in the case of a wound about the centre of the thigh, a provisional ligature placed on the common femoral artery fails to control the blood entering the profunda from its posterior anastomoses, and proves of little or no use. Again, the application of a provisional ligature or clamp necessitates either an enlarged or a separate incision, disadvantages to be avoided if possible.

The elastic ligature may be safely used to control the abdominal aorta for periods of at least a quarter of an hour, and in cases of urgency is a most valuable expedient.

Speaking generally, it is the method of choice in urgent cases and in dealing with early arterial hæmatomata.

Provisional ligature should be reserved for certain positions, such as the root of the neck or the groin, where it is not practicable to apply a tourniquet, or for cases, such as settled traumatic aneurysms, where the operation may be long and difficult.

A ligature is preferable to a clamp, as it may be applied with less disturbance of the parts, and needs less attention during the performance of an operation. It may suffice simply to pass a loop under the vessel when slight tension will control the circulation, but it is usually more convenient to tie a single surgical knot over a piece of drainage tube of calibre corresponding to that of the artery. A narrow tape or thick silk thread should be used. Rough handling of the vessel, or too tight tying of the knot, may result in the development of a local thrombus; hence the procedure demands delicacy.

The incisions for the operations need to be free in order to save time and to allow of exploration, since the actual site and extent of the wound can often be determined only when the vessel is exposed.

In certain situations, especially the thigh and ham, when primary hæmorrhage has been free and the patient is very

anaemic, the question of introducing a temporary conduit to maintain the circulation may be considered. The method introduced by Professor Tuffier has been employed by many surgeons, and to a certain extent in the British army. A silver tube of suitable calibre coated with paraffin is tied in between the divided ends of the vessel, and allowed to remain for some days; four may be taken as an average. The tube usually becomes occluded fairly rapidly—even in a few hours—in some cases gradually, and occasionally it may remain patent for ten days or more. The theory on which the method is based is to the effect that the peripheral circulation is gradually and not suddenly interrupted, and that the interval of decreasing patency allows time for enlargement of the collateral vessels.

Twelve cases in which Tuffier's tube was used are included in Series II: carotid, 1; femoral, 5; popliteal, 6. One patient died from gas gangrene, and one limb was amputated for septic infection, but in no instance did anæmic gangrene occur.

Questions arose as to whether the artery and vein should be occluded simultaneously. This practice was largely followed for several reasons. In cases in which both artery and vein were divided by the missile, and ligatured, no ill-effects were seen. In surgical practice large veins are often occluded without deleterious results. Contusion and thrombosis of the satellite vein in connection with division of the artery is not followed by bad results. In operations for arterio-venous aneurysms both vessels need to be occluded, and the results of the operation have been good. Senile gangrene of the foot has been prevented or retarded as a result of the rise in the local blood-pressure produced by ligature of the popliteal vein. When a fistulous communication has formed between an artery and vein, if the artery be tied on the proximal side of the anastomosis, the free backflow of arterial blood into the vein leads to a fall in the peripheral arterial blood-pressure and a decrease in the blood supply. This has been frequently observed to lead to gangrene in the lower extremity. Experiments by M. van Kerd showed that the local blood-pressure in the limbs of animals is raised when the vein is ligatured subsequently to occlusion of the artery. Hamilton Drummond showed that if a mesenteric artery alone is tied gangrene follows, while if both artery and vein be tied this does not occur.

On these grounds it was assumed that ligature of both vessels maintains a better balance in the collateral circulation, as the veins and arteries which carry it on more nearly correspond in size, and greater equality is ensured in the blood-pressure and rate of flow of the circulation.

It has not been found possible to extract any reliable information on this point from the notes of the cases included in Series I, but Table VI represents the immediate results as seen in the cases of Series II.

TABLE VI.

Comparative Result of Ligaturing Artery alone, and simultaneous Ligature of Artery and Vein.

Artery.	Artery alone.			Artery and Vein.		
	No. of Cases.	Good Result.	Gangrene.	No. of Cases.	Good Result.	Gangrene.
Subclavian	4	3	1	1	1	—
Axillary	6	5	1	4	4	—
Brachial	13	10	3	1	1	—
Femoral	32	24	8	32	25	7
Popliteal	24	14	10	28	22	6
Tibial	4	4	—	1	1	—
Carotid	18	12	6	4	3	1
Totals	101	72	29=28%	71	57	14=19.7%

Since the publication of these results, Dr. D. R. Hooker, at the request of Professor Halsted, has repeated van Kend's experiment on the dog, and reports as follows: A cannula was placed in a small branch of the femoral artery, and the external iliac artery was ligated, when the blood-pressure promptly fell from 114-26 mm. Hg. In the course of an hour the pressure rose to about 50 mm. Hg. In six observations in the period of an hour, in which the vein was also occluded from one to eight minutes the arterial pressure rose to 20, 12, 8, 3, 10 and 14 mm. Hg. Removal of the temporary occluding band from the vein was followed by a sudden fall in the pressure and a subsequent slow rise. This rise, however, never reached the level established when the vein was occluded.

At a meeting of the Inter-allied Surgical Conference held in Paris in May 1917, this question was discussed and the following conclusion adopted. "Contrary to what has until now been believed, simultaneous ligature of both artery and vein, when both vessels have been wounded does not give rise to increased risks of gangrene; in fact, it diminishes them. Facts tend to

prove, even when the wound is limited to the artery, that simultaneous occlusion of the unwounded vein is to be recommended."

It has not been possible to collect data as to the late results of this practice. The immediate advantage gained was definitely established, but of the ultimate effect on the limbs information is still wanting. A small number of patients is known in whom the ultimate result has left nothing to be desired, but some cases of removal of femoral arterio-venous aneurysms described on page 273 call for attention. It will be observed, however, that in each of the instances there recorded certain complications may be responsible for the condition of the limbs, and that such results are not in accord with general experience of the result of subjecting arterio-venous aneurysms to operation.

Table VII exhibits the results of ligature of the large vessels in 489 cases.

TABLE VII.

Artery.	No.	Gangrene.	Amputation.	Recovery.	Death.
Carotid—					
Proximal	33	12	—	29	4
Local	27	2	—	22	5
Subclavian—					
Proximal	11	—	—	9	2
Local	2	—	—	1	1
Axillary—					
Proximal	17	—	—	15	2
Local	52	1	—	46	6
Brachial—					
Local	73	—	4	72	1
Femoral—					
Proximal	12	2	2	8	4
Local	168	29	36	129	39
Popliteal—					
Proximal	10	1	2	7	3
Local	84	24	25	77	7
Proximal	83	15 = 18%	4	68	15 = 18%
Local	406	56 = 13.7%	65 = 16%	347	59 = 14.3%
Totals	489	71 = 14.5%	69 = 14.1%	415	74 = 15.1%

* 16 per cent. without carotids.

The comparative figures of proximal and direct local ligature in the table deal only with the questions of gangrene, secondary

amputation and mortality. The question of failure of proximal ligature to deal with the conditions for which it is undertaken and its dangers are recorded in the case of each vessel separately.

Suture of Wounds of the Blood-vessels.

Interest in this subject at the beginning of the war may be said to take a place similar to that felt concerning intestinal suture at the commencement of the South African campaign, and the ultimate history might have been the same had it not been for the long duration of the war, which permitted of efforts that had at first failed being repeated later.

Some attempts were made in the front line, but these were generally vitiated by infection of the wounds. The dangers of infection, and the fact that the injuries arrived at the most unsatisfactory date for plastic operations, prevented any material advance being made in the hospitals on the lines of communication. As conditions improved a small number of cases was, however, operated upon, and those which came under notice are briefly described in connection with individual vessels. The results may be summarized as follows:—

There were six cases of injury to the carotid arteries, all the operations being performed for the cure of traumatic aneurysms. All the cases recovered; in one instance the use of a part of the wall of the aneurysmal sac to reconstruct the artery led to temporary thrombosis, and the patient suffered from transitory cerebral signs. In one instance a second arterio-venous anastomosis of the same vessels was overlooked, and although the aneurysm treated was cured, a thrill in the lower part of the neck persisted. The patient refused a second operation and returned to his home in Canada. As far as it is possible to judge in the case of the carotid, the remaining four results were ideal.

Four operations for axillary aneurysm or varix were successful but in one thrombosis occurred, possibly not permanent, again as a result of employing a portion of the sac to reconstruct the artery.

Eleven operations on the brachial artery were performed, and all the patients were eventually cured as far as the aneurysm was concerned. Two accidents occurred, one primary end-to-end union giving way on the tenth day, and in the second primary operation the aneurysm recurred and had to be treated by ligature of the artery. Of the remaining cases one furnished an ideal result with normal peripheral blood-pressure, in two the

peripheral circulation was fairly maintained, and of the other six it can only be said that the result was, at any rate, as good as could have been attained by ligature.

Ten operations were performed on the femoral artery. Two deaths occurred in this series—one a case of primary suture from acute infection of the surrounding wound, and the second from infection spreading from an overlooked sinus in the buttock. The remaining eight cases all furnished satisfactory results; in two of them the peripheral blood-pressure was only slightly below normal.

Eight operations were performed on the popliteal artery. One case of primary suture died from infection of the wound. Of the remaining seven, one result was ideal, two were good, and in four thrombosis certainly occurred.

The total number of cases thus operated on amounts to thirty-nine and of these about one-half were successful. Of those remaining three died, two after primary and one after secondary operation, all from infection; the others furnished results in no way inferior to those of ligature.

There can be little doubt that many other operations were performed in the British army, but no histories of these are available. A note of five cases included in a series of traumatic aneurysms treated in the hospitals in the United Kingdom may be added.

Case 1.—Popliteal aneurysm of two months' standing. A smooth lateral opening sutured from the cavity of the sac. No mention is made of the peripheral pulse subsequently to the operation.

Case 2.—Femoral arterio-venous aneurysm. Lateral opening in artery sutured on tenth day from the cavity of the sac. Vein untouched, recurrence of the anastomosis, but no extension of pre-operative gangrene.

Case 3.—Axillary aneurysm. Lateral wound in vessel sutured on third day. Radial pulse improved after operation.

Case 4.—Brachial aneurysm. Small lateral opening closed on ninth day by "a circular suture of very fine thread passed in the arterial wall and around the opening, and tied." Radial pulse present next day, and persisting as "small, fair" on seventy-fourth day.

Case 5.—Popliteal arterio-venous aneurysm. Lateral suture of artery and end-to-end anastomosis of vein, at end of five months. Five months later the circulation was normal and the patient was on "light duty."

The material afforded by forty-four cases is scarcely sufficient to dogmatize upon, but it is clear that half the operations furnished admirable results, while the remainder could compare with any series of occluding operations.

The following deductions may reasonably be arrived at with regard to suture of blood-vessels:—

Suture of wounded blood-vessels is the only method by which ideal results can be obtained.

The method is only applicable in the primary stage if reasonable expectation of maintaining the wound free from infection exists.

Intermediate operations are not to be advised between the second and the tenth day. Only in exceptional instances are the wall of the artery and the surrounding tissues in a satisfactory condition for plastic measures.

Even when the intermediate stage is passed a further lapse of time up to three months will render the procedure more easy and give a greater chance of a perfect result.

Lateral wounds involving not more than one-third of the calibre of the vessel are the most suitable for closure by suture. If primary operations are done, every care must be exercised to determine the extent and degree of associated contusion.

If more than one-third of the calibre of the vessel is destroyed an end-to-end union must be made after resection of the injured portion. These operations are advisable only if the vessel can be mobilized without the division of uninjured branches, and provided no great flexion of the limb is required to bring the ends into easy apposition.

Reconstruction of a vessel by employing flaps derived from the adventitious sac of an aneurysm is not advisable. Such reconstructed arteries eventually dilate, and they usually become thrombosed, and thus afford a risk of embolism, or of permanent obliteration. Neither should the line of suture be reinforced by flaps of alien tissue, a method likely to be followed by cicatricial contraction.

Should a thrombus form rapidly before the external wound is closed, it should not be removed. It will almost certainly re-form, while evidence exists that such thrombi are firmly attached along the line of the wound only if the intima has not been injured elsewhere. Their tendency is to shrink, cicatrize, and undergo absorption; thus the circulation may gradually be re-established.

The most satisfactory arteries for the method of suture are the carotid, the femoral and the popliteal. The axillary and brachial come in the next category. The smaller arteries will scarcely repay any surgeon not a past-master of technique.

It is unnecessary to use needles and silk so fine as those employed by Carrel in his experimental work. The needle may be twice that size and calibre, and the same may be said about the silk (Japanese 0000). The use of very delicate needles and silk makes the technique much more difficult and exacting.

It is much to be desired that prolonged observation be maintained of patients on whom suture operations are performed as the tendency to secondary contraction is undoubted. It may, however, be asserted with confidence that, even if subsequent occlusion occurs, yet, as this is a gradual process, the eventual peripheral supply will be superior to that following any operation which produces a sudden complete occlusion.

The Treatment of Traumatic Aneurysms.

Although in such statistics as are quoted no distinction is drawn between cases of hæmatoma and aneurysm, because for the most part the surgeons concerned have used the terms synonymously, the two classes of case are in no sense identical either with regard to the risks and dangers which attend them, or as to the methods of operation suitable.

The hæmatoma stage is that in which the patient is exposed to urgent risks, such as rapid enlargement, extension beyond the original boundaries, secondary hæmorrhage and infection. These risks are greater in the arterial than in the arterio-venous variety for reasons already given.

Prompt intervention is called for when there is continuous hæmorrhage or even leaking from the external wound ; rapid increase of size, or diffusion into the surrounding area ; obliteration or progressive diminution of the peripheral pulse, due to local pressure on the main trunk or general indications of incipient gangrene ; signs of pressure on neighbouring structures, veins, nerves, or viscera ; secondary hæmorrhage or signs of extending infection of the bounding structures.

Failing any of these indications an expectant attitude is preferable at this stage, especially if recent severe primary hæmorrhage has occurred. The necessary operation can rarely be performed with no further loss of blood, and loss of blood at this period may involve the death of the patient or of his limb. An expectant attitude is also preferable if the tissues are in an unfavourable condition for operative manipulation, and the risks if infection takes place are great ; if clot needs to be removed from a large and irregular space, the tissues are infiltrated, cedematous and unyielding, and the arterial wall is in a similar condition. These local anatomical conditions practically preclude the closure of the wound in the vessel by suture, the ideal to be aimed at.

With the rare exceptions in which a local operation is impracticable, direct ligature applied on either side of the wound is the only proper method.

The routine procedure commences with the application of a tourniquet, or provisional proximal control of the vessels by ligature or clamp. In rare instances the hæmatoma may be opened, the rush of blood controlled by digital pressure on the wounded spot, and the artery rapidly tied above and below; such procedure, however, should never be followed if it be avoidable. When the wound is not of the main trunk the spot may be difficult to find in the mass of more or less adherent blood clot, and in any case more blood is lost than is either necessary or safe.

If the circulation be controlled, a large incision such as is needed may be made without fear, and the wound in the vessel may be sought for without haste and more cleanly and securely dealt with. This statement is still more justified when both artery and vein are wounded.

The application of a proximal ligature fails to relieve the local tension, it reduces the capacity of collateral supply by abrogating branches between the site of ligature and that of the lesion, it involves the risk of continuing hæmorrhage from the artery on the distal side of the wound, and it is a procedure which extended experience has proved to be unsatisfactory and dangerous.

The treatment of arterial traumatic aneurysms does not materially differ in principle from that of the arterial hæmatoma, but greater variety of procedure is available.

Series I and II combined include 187 cases of aneurysm treated by ligature with the following results. More details concerning these cases will be found below.

TABLE VIII.

Cases of Aneurysm treated by Ligature.

Variety.	Number.	Gangrene.	Amputa- tion.	Recovery.	Death.
Arterial.. ..	115	8	—	98	17
Arterio-venous..	72	10	6	61	11
Totals ..	187	18	6	159	28

A series of cases treated by surgeons in the hospitals in the United Kingdom affords a good general idea of the methods in vogue.

TABLE IX.

Traumatic Aneurysms treated in Hospitals in the United Kingdom.

Artery.	Number.	Proximal Ligature.	Direct Ligature.	Suture.	Excision.	Arterial Aneurysm.	Arterio-venous Aneurysm.	Aneurysmal Varix.	Recovery.	Death.
Common carotid.. ..	5	1	—	—	2	2	3	—	4	1
Both C. carotids	1	1	—	—	—	—	—	—	1	—
Ext. carotid	2	—	1	—	1	—	—	—	2	—
Int. carotid	1	1	—	—	—	—	1	—	1	—
Subclavian	2	—	1	—	—	1	1	—	1	1
Axillary	8	2	4	1	1	6	2	—	8	—
Brachial	8	—	4	2	1	6	2	—	8	—
Radial	2	—	2	—	—	2	—	—	2	—
Ulnar	3	1	2	—	—	2	1	—	3	—
Femoral*	19	5	7	1	3	6	9	2	15	4
Popliteal	16	3	9	1	2	10	2	3	16	—
Ant. tibial	1	—	1	—	—	—	—	1	1	—
Post. tibial	5	1	2	—	2	3	3	—	4	1
Peroneal	1	—	—	—	1	—	1	—	1	—
Peron. and both tibials ..	1	—	1	—	—	—	1	—	1	—
Facial	1	1	—	—	—	1	—	—	1	—
Temporal.. ..	1	—	—	—	1	—	1	—	1	—
Totals	77	16	34	5	14	38	27	6	70	7

* Including three of profunda.

Five cases no operation. One primary amputation. Gangrene in three femorals. Three failures after proximal ligature.

Excision of the aneurysm has proved successful in the hands of all surgeons. The number of cases included in Series I and II is small, sixteen in all, but the whole number recovered and cures are reported. In the fourteen cases quoted in Table IX the same satisfactory result occurred.

In the face of these results, it would seem unnecessary to criticize a method which has been generally approved, but the results are not ideal, since the circulation in the main trunks is obliterated to a considerable extent, and while recovery is commonly attained yet the general nutrition of the limb must suffer. Operations for the excision of large aneurysms demand an extensive dissection during which a number of small collaterals which would have proved of definite value are wounded. Equally good results follow ligature

of the vessels in direct proximity to the aneurysm, provided care be taken, especially in arterio-venous aneurysms, that no branch is left in direct communication with the sac.

Suture as a method of treatment of traumatic aneurysm has been sufficiently dealt with above. When practicable, and efficiently performed, it is the best method of treatment either for wounds or for traumatic aneurysms.

The following generalizations may be laid down as to the treatment of traumatic aneurysms.

Spontaneous consolidation is rare ; it occurs most frequently in the case of popliteal aneurysms, hardly ever in arterio-venous aneurysms.

Direct ligation of the vessels implicated is the method generally applicable to all cases.

Proximal ligation is never to be resorted to except in cases where it is unavoidable.

Direct ligation may be combined with excision of the aneurysmal sac. This method is to be avoided if it requires extensive dissection involving injury to collateral arterial branches, or risk of injury to neighbouring structures. Its main advantage lies in the prompt removal of tissue which otherwise may be slow of absorption.

In exceptional cases, and in certain positions, such as the root of the neck, distal ligation has proved of utility.

When practicable, suture of the wounds of the larger vessels should always be considered as the ideal to aim at. The greater length of time demanded for its performance and the need for technical skill are the main disadvantages which can be urged against the method.

When an aneurysmal sac has been laid open, after the establishment of provisional control of the circulation, suture of the open ends of the vessels is easy, safe and preferable to ligation which demands freeing of the vessels for a certain length.

Arterial aneurysms, although they show an initial tendency to contract and localize, usually enlarge again when the patient resumes ordinary life. All require surgical intervention.

Arterio-venous aneurysms do not show the same tendency to enlarge, but in active life the venous obstruction increases, and as a general rule operation is advisable or necessary.

Aneurysmal varices may often be disregarded, especially in the upper extremity or in the case of small vessels. When they give rise to pain, or serious venous obstruction, suture of the anastomotic opening through the laid-open vein is easy

and effective. Occasionally a ligature passed between the two vessels and tied around the communication is practicable and gives good results. Ligature of the vessels or excision of the varix is not warranted in view of the success which attends the above-mentioned methods and the ideal result obtained by them.

An examination of the results described in connection with injuries of the individual vessels will be disappointing, but it must be borne in mind that gunshot injuries to the blood-vessels are seldom free from complications due to laceration of the surrounding soft parts and that fractures of the bones are often present. Hence they are to be regarded as a class by themselves, and not to be considered as exemplifying the consequences of simple ligature or obstruction of the lumen of an artery. The results, however, show that much remains to be done in improving the method of dealing with these injuries, and in the light of present knowledge the direction in which efforts must be made lies in the acquisition of increased familiarity with the technique of suture of wounds of the vessels.

CHAPTER VII.

INJURIES TO THE VESSELS OF THE TRUNK AND NECK.

Aorta.

THE great majority of the men who sustained an injury to the aorta without doubt succumbed, and wounds of the great artery of the trunk accounted for a large proportion of the fatalities due to gunshot injuries to the chest and abdomen. Evidence, however, has accumulated to show that clean perforations of the vessel by bullets and minimal wounds caused by small metallic fragments may heal spontaneously.

The following cases illustrate this :—

Case 1: Bullet Wound of the Thoracic Aorta.—The patient sustained a perforating wound of the chest, and during the next twenty-four hours was operated upon, and four pints of blood were evacuated from the right pleural cavity. The wound underwent a severe streptococcal infection, and as a result the patient died on the fifth day after reception of the injury. At the autopsy the areolar tissue of the posterior mediastinum was found to be densely infiltrated with blood-clot, but no aneurysmal cavity was present (Fig. 1). A slit aperture of entry was found in the descending aorta, and the bullet which had caused this wound was discovered in the right common iliac artery with the base directed downwards. There is no reason to assume, from the conditions discovered after death, that this patient might not have recovered so far as the aortic injury was concerned. The hæmothorax was probably entirely due to the accompanying wound of the lung, as no direct track in the infiltrated mediastinal tissue was visible.

Case 2: Traversing Wound of the Abdominal Aorta.—The patient, aged 32, was admitted to hospital five days after receiving two wounds, one in the left axilla, the second just within the vertebral border of the left scapula. The wounds were almost healed at the time of admission, and it was at first thought that the thorax had not been penetrated. The injury had been followed by moderate hæmoptysis and some dyspnœa, but by no abdominal pain.

When admitted to hospital on the fifth day the patient was slightly dyspnœic, but there were no abdominal signs; the temperature was 101·6° F., and the pulse-rate 116. The signs discovered in the chest were slight, and considered to indicate either a small hæmothorax or a traumatic pneumonia. An X-ray examination showed slight opacity at the left base, and the outline of the diaphragm was obscured. An exploring needle, entered at the left base, gave a negative result. The abdomen was supple and not tender; there was slight jaundice of the conjunctivæ.

During the next few days the patient's general condition improved; the evening temperature rose to 101° to 102°, but the pulse-rate averaged only 88.

On the seventeenth day after the injury the man began to vomit freely, and complained of pain all over the abdomen; the latter remained supple, but was tender throughout and distended. A rectal examination afforded no information. The signs in the chest had cleared up, except for evidence of slight bronchitis in both lungs.

All food by mouth was forbidden, pituitrin was administered subcutaneously, and dextrose was given by enema. These measures relieved the vomiting and distension, but the abdominal pain persisted, and on the twentieth day

became localized in the right half of the abdomen. Some resistance to palpation now developed, especially in the right iliac fossa. A repeated rectal examination proved negative. The temperature was 101° , and the pulse-rate had risen to 100.

A diagnosis of appendicitis was made, and a laparotomy performed. The operation disclosed little beyond the existence of generalized distension, and some old adhesions in the region of the appendix; there was no excess of peritoneal fluid.



Fig. 1.—Bullet wound of thoracic aorta, fifth day, Infiltration of mediastinal connective tissue with blood, but no aneurysmal sac.

The pain and vomiting continued, the temperature remained high, the pulse became progressively more rapid and weaker, and on the twenty-third day the patient died; there was never any hematuria, and the coloration of the conjunctivæ had not appreciably increased.

* At the autopsy, on incising the scar an inch below the left axillary folds, just posterior to the mid-axillary line, a track leading to the left pleural cavity could be distinguished. No track could be detected leading from the

* The specimen of this case is in the War Office Collection.

scar at the vertebral border of the scapula. Half a pint of bloody fluid was found in the left pleural cavity, and tenacious adhesions were present in both pleuræ, between the lung and chest wall. The upper and the inner surfaces of the sixth rib were grooved and denuded of periosteum.

An aperture half an inch in diameter was found in the diaphragm, near the mid-line and towards the back of that portion of the muscle in contact with the inferior surface of the lower lobe of the left lung. The opening was partially closed by a tag of omentum, which adhered to its margin.

The myocardium was paler than normal, and broke down with moderate digital pressure. The pericardium, endocardium, and valves were normal.

A moderate quantity of clear brownish fluid was found in the peritoneal cavity, there was neither blood nor pus, nor any evidence indicative of recent peritonitis. The spleen was enlarged, soft, and of an opaque pink colour. The liver was enlarged, soft, and yellow in colour. On section, a fatty area was seen at the upper aspect of the left lobe, corresponding in position with the overlying aperture in the diaphragm. The connective tissue of the capsule was infiltrated with blood. The fundus of the gall-bladder was adherent to the transverse colon, the organ was not distended, and its contents were normal in character. The kidneys were somewhat swollen, soft, and pale. They presented no sign of injury. The pancreas was embedded in blood-clot, but no sign of interstitial hæmorrhage was seen on section.

The entire retroperitoneal tissue was infiltrated with soft blood-clot, the mass being greatest in the right renal region, and around the right crus of the diaphragm and the pancreas. When the right kidney had been removed by division of the vessels entering the hilus, a small, more or less cylindrical fragment of metal, measuring one-half by one-quarter of an inch, was found in the clot near the pedicle. Two apertures were found in the aorta, just above the level of origin of the renal arteries. One opening was triangular in shape, with a small flap, the other was oval with ragged margins. The openings permitted the passage of the fragment of metal introduced lengthwise (Fig. 2).

The lumen of the vena cava could not be clearly distinguished on account of the firm clot.

Captain Bethune, who performed the autopsy, makes the following remarks: "The post-mortem evidence points to septicæmia as the cause of death. It is remarkable that neither blood nor blood-clot was seen in the peritoneal cavity, either at the operation performed on the seventeenth day or at the post-mortem examination made upon the twenty-fourth. Had there been a hole in the posterior peritoneal layer, death would surely have occurred rapidly from hæmorrhage into the peritoneal cavity. The conditions found on both occasions suggest that the projectile passed through the lesser sac of the peritoneum, subsequently travelling in the subperitoneal tissue of the aorta. If one may assume that the man was lying on his face when he received the wound in the axilla, the escape of the stomach and liver from injury may be accounted for by the falling forward of these viscera towards the anterior abdominal wall. One other point is deserving of notice, namely, that no suppuration or abscess was found in the clot or elsewhere, which might have acted as a focus for the septicæmia."

It is evident that in neither of these cases could a diagnosis have been made, while in the absence of complications either patient might have survived and suffered no material disadvantage.

Traumatic aneurysms, on the other hand, have not been reported; the following instances of arterial hæmatoma, although they illustrate wounds of the aorta which might have been immediately fatal, yet show that the development of an actual false aneurysm has made but little progress.

The enormous force of the blood-stream and the non-resistant character of the structures surrounding the aorta form a ready explanation of this observation, and it is probable that the possibility of this stage of development being reached depended on the low blood-pressure which accompanied the shock consequent on the original injury.



Fig. 2.—Bilateral perforation of abdominal aorta by shell fragment.

Case 3: Wound of Thoracic Aorta.—Fig. 3 (War Office Collection) is an excellent example of a large arterial hæmatoma in connection with the thoracic aorta. This and the following specimen are both remarkable in illustrating how large a rent may be made in a great trunk vessel without leading to rapid death. In this specimen the widespread attachment of the provisional sac to the outer surface of the vessel is a prominent feature. The cavity of the sac probably represents the original pool of blood which formed when the vessel was injured, while the wall of the sac is formed by blood-clot, deposited at the periphery, and layers of mediastinal connective tissue stiffened by hæmorrhagic infiltration.

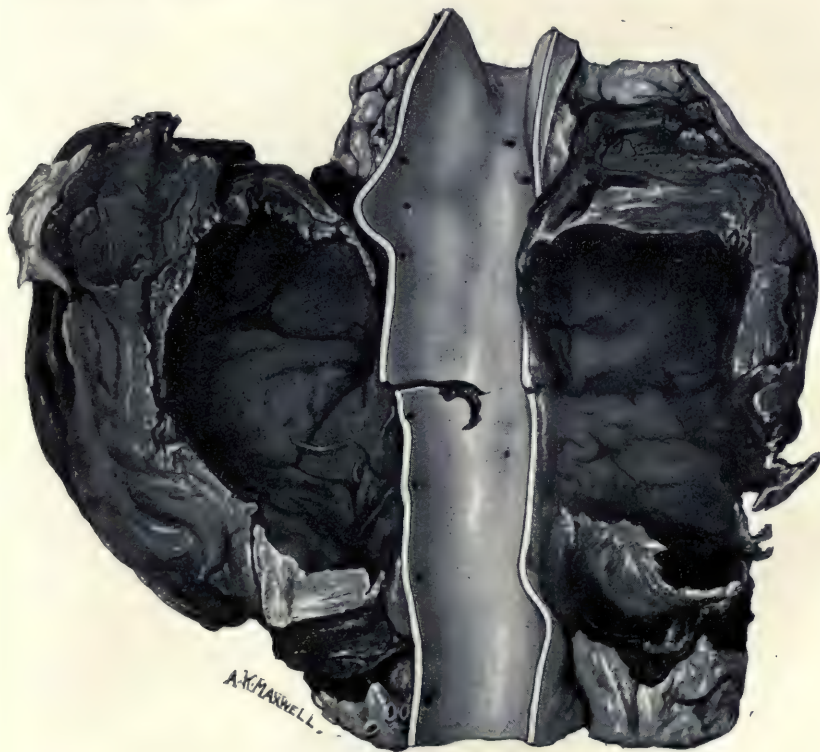


Fig. 3.—Arterial hæmatoma in connection with a wound of the thoracic aorta.

Case 4: Wound of Thoracic Aorta.—Death from hæmorrhage from the hæmatoma. Fig. 4 (War Office Collection) shows an aneurysm in connection with an extensive transverse slit in the posterior surface of the thoracic aorta near its commencement. The patient survived a series of very serious injuries for a period of thirty-seven days. Struck by fragments of a bomb, he received multiple wounds in the back and buttocks. For four days after the injury he lay out in No-Man's Land, and when brought into hospital he was suffering from "trench" hands and feet. On the ninth day several fingers and both feet were amputated for gangrene. The wounds in the back and buttocks were infected, but going on well. On the twenty-eighth day he complained of severe pain in the chest ("deep in"). The pain was increased

on swallowing, and the temperature rose to 101.4° . From this period the temperature remained high, and the pain in the chest continued. On the thirty-seventh day a sudden violent hæmorrhage occurred, blood escaping by the mouth, and the patient died.

At the autopsy, the amputation stumps were granulating. About half a pint of turbid fluid was present in each pleura; on the left side there was much plastic exudation. The lungs were œdematous, but not pneumonic. The heart was dilated, but there was no valvular disease. The solid abdominal viscera

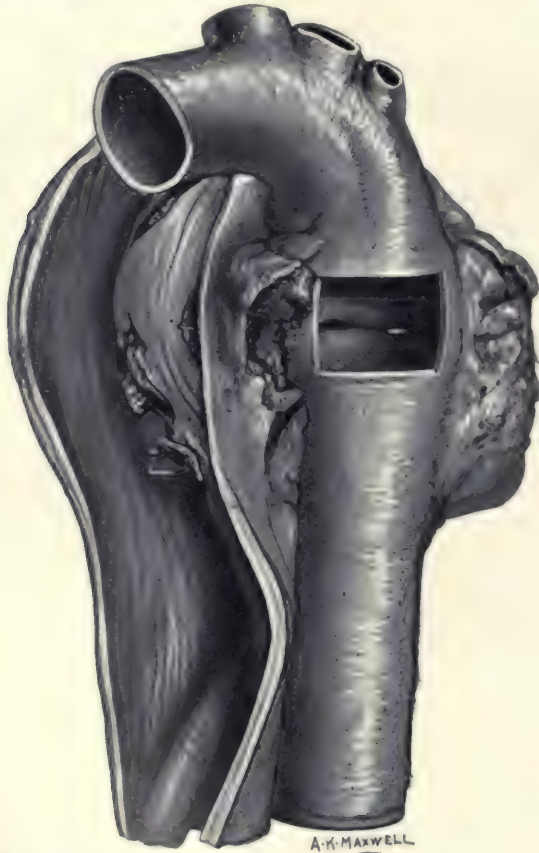


Fig. 4.—False aneurysm of thoracic aorta. (Esophageal ulceration and perforation of wall of sac.

were in the condition characteristic of general septic absorption. The stomach was distended with recent blood-clot, but otherwise normal. The œsophagus was normal in the lower third, but bulged forward prominently behind the bifurcation of the trachea. At the bulging portion the wall of the œsophagus, when displayed from within, exhibited three rents, as seen in the illustration. These rents led to a thick-walled cavity filled with clot communicating with the interior of the aorta by a slit-like orifice. Captain Shore speaks of the cavity as "apparently inflammatory," but regarded it as a false aneurysm.

The specimen appears to illustrate the comparatively rare sequence of secondary infection of an aneurysm, in all probability occurring as a complication of ulceration of the surface of the œsophageal wall where bulged inwards by the prominence of the sac.

Case 5: Wound of Abdominal Aorta.

—Death from septicæmia on sixteenth day. Fig. 5 (War Office Collection) shows an extensive obliquely transverse wound of the aorta, between the origins of the superior and inferior mesenteric arteries. The attachment of the walls of the hæmatoma at some distance from the actual wound of the artery shows that there is here the wall of an early arterial hæmatoma, for in a fully developed false traumatic aneurysm the margin of the sac corresponds exactly with that of the aperture in the wall of the artery. The patient from whom this specimen was removed had suffered very extensive injuries. There was a wound of the left side of the thorax through the seventh rib, whence the bullet passed through the diaphragm, wounded the left lobe of the liver, and finally the front aspect of the abdominal aorta below the superior mesenteric artery. A second bullet entered the left leg, and caused a comminuted fracture of the patella.

The man was admitted into the field ambulance the day after he was wounded, and thence was sent down the line, and eventually to England, during the German offensive in March 1918. He arrived in No. 16 Canadian General Hospital on the seventh day, in fair condition; the chest wound was healing well, but the wound of the knee-joint had become infected and was suppurating. A collection was diagnosed in the left pleural sac; this was aspirated, and about twenty-five ounces of bloody fluid were evacuated. The patient gradually lost ground, and died on the sixteenth day after reception of the injuries, as a result of loss of blood and toxæmia.

At the autopsy the visceral lesions already enumerated were discovered, also a small omental hernia through the rent in the diaphragm. There was very copious retroperitoneal hæmorrhage, extending from the upper border of the kidney along the line of the ascending colon to the pelvis. The pelvis was filled with blood, and a sac with walls of clot three to four inches in thickness had formed in connection with the wound of the aorta.

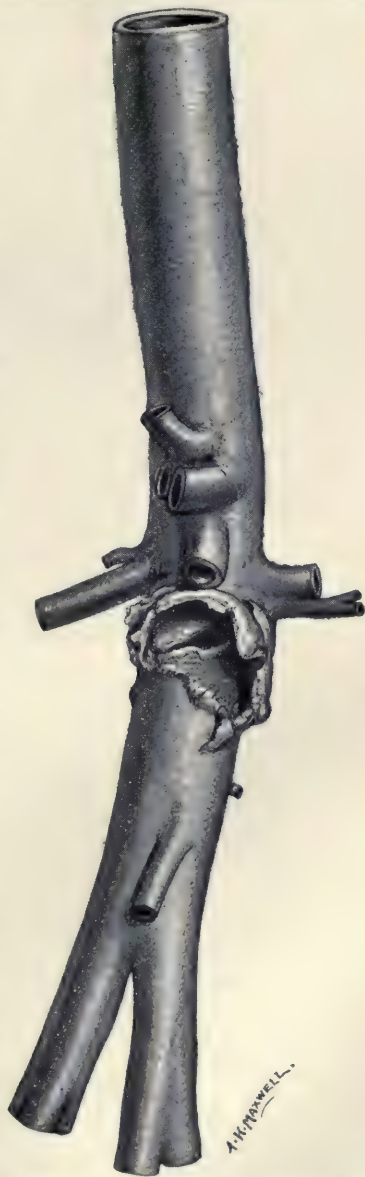


Fig. 5.—Wound of abdominal aorta with remains of sac of arterial hæmatoma.

Attention is drawn to two points in connection with wounds of the abdominal aorta. The first point is the very large amount of blood which may infiltrate the retroperitoneal connective tissue. The blood clots rapidly and a mass even some inches thick is deposited at the back of the abdomen and pelvis. The rapid clotting is due to the fact that the infiltration of the tissue with blood is accompanied by tearing of the structure and consequent escape of tissue juice, and to the irregularity of the boundaries of the potential space formed. If blood at the same time passes into the peritoneal cavity it remains fluid for a considerable period. Putting aside the question of loss of blood, these retroperitoneal hæmorrhages furnish another source of great danger in the frequency with which they become infected from the intestine. Abdominal injuries thus complicated were commonly those in which acute gas gangrene developed during the first twenty-four to forty-eight hours.

The second point relates to the frequency with which these injuries occurred in the abdomino-thoracic class, and hence formed one of the sources of the formation of a hæmothorax.

The Innominate Artery.

One undoubted case of arterio-venous aneurysm is included in Series II.* It was shortly as follows :—

Case 6: Innominate Arterio-venous Aneurysm.—Death from secondary hæmorrhage on the tenth day.

The patient, aged 19, was wounded by a small fragment of shell, which entered over the centre of the right suprascapular spine, and was retained in the chest. He was kept at rest at the casualty clearing station for some days, and then transferred to a hospital on the lines of communication. He was brought to the notice of the surgeon on the seventh day after reception of the wound, as suffering with congenital heart mischief, the diagnosis having been made as a result of the roaring murmur audible in the præcordium and at the back of the chest. He was then somewhat cyanosed and dyspnoëic, but not in great distress. He had expectorated a good deal of blood for the first two days after the injury, but none since; the temperature was normal: the pulse-rate 120.

On palpation some pulsation and a purring thrill were detected above the right clavicle. The right apex was dull on percussion, and the breath sounds were diminished and tubular at the right base.

On the evening of the same day the patient died as a result of a profuse hæmoptysis.

At the autopsy a wound the size of the little finger-nail was found on the anterior surface of the root of the innominate artery; the wound of the vein could not be localized. The apical area of the pleural sac was obliterated by old adhesions, hence the absence of a hæmothorax. The sac was formed by an old tuberculous cavity in the apex of the right lung, and within its confines a small sharp fragment of shell was found.

* For explanation of Series I and II see Chapter VI.

In two other cases an innominate varix was suspected, and one suspected case is included in Series I. One of these cases may be quoted in illustration.

Case 7.—The patient was admitted with a small slit entry-wound, situated over the left sterno-clavicular joint. The missile was retained and its position was never discovered. The patient was suffering from an extensive right hæmothorax, and was very ill. During the next ten days he improved, and meanwhile the whole chest was examined almost daily, and was also aspirated.

On the eleventh day a double machinery murmur was heard for the first time by Lt.-Colonel T. R. Elliott, under whose observation the man had been since his admission. The systolic element was of the "slamming" or "pistol-shot" character, the roar was conducted loudly to both sides of the neck and to the base of the heart. A bubbling thrill was palpable in the line of the right axillary vein. A week later there was little change, except that the thrill was now felt only in the line of the jugular vein in the neck, and that the murmur was louder and more definitely localized over the line of the innominate vessels. No local dullness was to be detected beneath the first piece of the sternum, or in the upper right intercostal spaces. The patient was shortly afterwards transferred to England.

It must be extremely rare for the question of operative treatment of innominate aneurysm to arise. In the suspected cases, the signs diminished, and the patients improved with rest. A case occurring in the South African campaign was watched for five and a half years, at the end of which period the bruit due to the arterio-venous communication disappeared, the man meanwhile following his occupation as a lamp trimmer. It is probable that all these cases were varices with a limited aperture of communication between the artery and the vein.

In the case of an arterial aneurysm, the question of distal ligation of the carotid and subclavian might be considered.

More practical interest lies in the operation of ligation of the vessel, for the treatment of aneurysms at the root of the neck or for hæmorrhage. The vessel also needs occasionally to be exposed for the application of a provisional ligation.

Notes are given of two cases in which the innominate was ligatured for the cure of aneurysm.

Case 8: Ligation of the Innominate Artery for Traumatic Aneurysm of the Common Carotid.—An officer, aged 20, was struck by a bullet, which, entering in the lower part of the right anterior triangle, emerged close to the superior angle of the scapula on the same side. He bled profusely and became very anæmic. A traumatic aneurysm of the lower end of the carotid formed and steadily enlarged. At the end of the fourteenth day it was as "large as an orange," $4\frac{1}{2}$ in. in width by 4 in. in length. Hoarseness developed in the later days. Respirations, 24; pulse, 100–112; temperature, 100–101·8° F.

The artery was exposed by a rectangular incision in the mid-line and along the clavicle. After detachment of the sternal head and part of the clavicular head of the sterno-mastoid, and partial division of the sterno-hyoid and sterno-thyroid muscles, it was found that no space was available between the clavicle and the aneurysm. Therefore, one and a quarter inches of the inner end of this bone were resected. The apex of the lung, with its uninjured pleura appeared in the dissection. The inferior thyroid veins and the larger veins

were retracted without damage; in fact, no minor artery or vein was clipped or ligatured throughout the operation. The innominate artery was found behind the middle of the manubrium, and in tracing it upward it became apparent that the common carotid was so incorporated in the aneurysm that the placing of a ligature upon it was impracticable, and therefore the innominate was tied with a single strand of No. 4 thirty-day catgut. The muscles were repaired with catgut sutures, and a small drain tube left in for forty-eight hours.

The question of a distal ligature was not debated, in obedience to the commonly accepted principle that the wounded artery should be doubly ligated and the contents of the sac turned out, or the sac excised; but these measures were advisedly omitted in this instance, lest a copious bleeding from the sac in a markedly anæmic subject, or the prolonging of an already lengthy operation should jeopardize the patient. It was intended that a distal ligature should be placed on the carotid some days later, should the progress be unsatisfactory. Fortunately, the need for this step did not arise.

The subsequent course was uneventful; no septic changes from the original bullet track were propagated to the operation wound; and the patient was evacuated to the base on 16th September 1916.

On 13th December 1916, three months after operation, an examination of the patient showed that no cerebral deterioration had resulted; his mental functions were normal. The vision of the right eye was perfect, though the vessels in the fundus were slightly reduced in size. There was no giddiness or disturbance of equilibration. The thrill, bruit, and pulsation could not be detected, and the aneurysmal swelling had entirely disappeared. A degree of muscular atrophy and the absence of the end of the clavicle rendered this examination more easy and convincing. Radial and ulnar pulses had not returned at the wrist; the circulation and sensation in the hand were good, but some feebleness with stiffening at the fingers remained, due probably to the prolonged disuse of the extremity rather than to tropho-neurotic changes. No doubt massage and exercises will remedy this temporary disablement. A satisfactory pseudo-arthritis had formed with the first costal cartilage, and active shoulder and elbow movements were good.

A second case is recorded below, in which the vessel was ligatured for the treatment of an arterio-venous aneurysm of the first part of the subclavian artery. In this instance, slight weakness of the left side of the body developed at the end of ten days and then slowly improved.

A case in which the artery was exposed for provisional control is also recorded below.*

The cases illustrate the two methods, resection of the sternal end of the clavicle and the use of the angular incision and division of the sterno-mastoid, and sufficiently indicate the reasons for their respective choice.

Four cases of ligature for the control of secondary hæmorrhage are included, two in each series. All four patients died, three on the day of operation, the fourth from secondary hæmorrhage at the seat of ligature, at the end of ten days, during which the patient had been transferred from France to England. In no case did cerebral disturbance follow, and all were the subjects of septic wounds and suffering from systemic absorption.

* See p. 247, Case 21.



Fig. 6.—Arterio-venous hæmatoma in connection with the external iliac vessels. Separate openings of artery and vein.

The Pulmonary Artery.

This artery and its branches, although frequently injured in wounds of the chest, offer little scope for surgery.

Two cases of arrest of the missile in branches of the trunk are, however, worthy of mention.

Case 9: (War Office Collection.)—A bullet wounded the back of the left external iliac artery, and then entered the vein (Fig. 6). Thence it was carried by the blood-stream to the right auricle, through the ventricle, and lodged in one of the lower branches of the left pulmonary artery. An arterio-venous hæmatoma formed in the left iliac fossa, and at the end of a week the left leg became gangrenous, and was amputated below the knee. After a few days, gangrene appeared in the amputated stump, respiration which had always been shallow and rapid became gasping, and the pulse-rate rose. Finally the temperature steadily mounted, respirations reached 60-70 to the minute, the pulse became uncountable, and the man died in a state of coma one month after receipt of the injury.

Captain Fry remarks that from measurements *in situ* and standard measurements, the distance travelled by the bullet in the blood-stream was not less than two feet. Since the blood-pressure in the inferior vena cava in the normal condition is about +3 mm. Hg, and diminishes in the veins of the chest and the right auricle to -8 mm. Hg, while the velocity of the circulation is not above 25 cm. per second, it is probable that the blood-pressure in the abdominal veins must have been greatly increased through the formation of the arterio-venous aneurysm, to have enabled the venous flow to sweep such a comparatively heavy weight as 10 grm. along the veins. The condition, indeed, was one in which the patient was bleeding into his venous circulation.

Case 10: Bullet in the Pulmonary Artery.—Viannay records a case where there was a large hæmothorax and hæmopericardium, and X-ray examination demonstrated a bullet near the hilus of the left lung, moving synchronously with the heart-beats. Viannay operated twenty days after the date of wounding, and was able to control hæmorrhage by compression of the root of the lung between finger and thumb; he clearly saw the tear in the pulmonary artery. After the compression was relaxed hæmorrhage was so violent that he had to close the opening by hæmostatic forceps, and then by ligature. He was unable at the time to be certain whether he had ligatured the whole pulmonary artery or only a branch; the subsequent occurrence of massive gangrene of the lung decided this point. Viannay thinks that it would have been better to have done a primary pneumectomy, but doubts if the patient would have recovered.

Iliac Arteries.

Wounds of the iliac vessels undoubtedly accounted for the fatality in many cases of abdominal hæmorrhage. Yet no case of injury to these vessels is found in Series I; such cases either died or have been included in the abdominal category.

Case 11:—Complete severance of common iliac artery. Hæmothorax. Death on thirteenth day.

The patient was wounded by a fragment of a trench mortar shell, which entered to the left side of the lower dorsal vertebræ. A hæmothorax developed promptly, and eight to ten hours after being wounded the man began to complain of pain in the left lower limb, which became swollen.

After a stay of nine days at the casualty clearing station, the patient was transferred to a hospital on the lines of communication. When admitted he

looked pale and ill; he was restless, with a good deal of cough, and a small amount of blood-stained mucus was still being expectorated. A hæmothorax, extending up to the angle of the scapula, was present, and on examination of the abdomen resistance to pressure was detected in the left flank and iliac fossa.

The right lower limb was thin and wasted; the left swollen, but with no subcutaneous œdema, and the calf muscles were firm and resistant on palpation. Sensation was present throughout the limb, and there was no loss of motor power.



Fig. 7.—Arterial hæmatoma developing in connection with a complete severance of the left common iliac artery. The cavity laid open and a portion of the clot still in position.

The man was very restless, and complained much of pain in the left lower limb which on the thirteenth day became more tense, and pulsation in the femoral vessels was ablated. Sensation became impaired in the thigh, and, although the limb remained warm, the foot commenced to be discoloured and mottled. On the fifteenth day the man died suddenly from no obvious cause.

At the autopsy, a pint and a half of blood was found in the left pleural cavity, and the track of the missile was traced through the base of the left lung, diaphragm, and psoas muscle. After emerging from the last, the missile had completely severed the common iliac vessels near their commencement (Fig. 7), and then dropped into Douglas' pouch. The femoral vein was thrombosed as low down as the popliteal space. A pint of bloody fluid was present in the peritoneal cavity, there was extensive retroperitoneal extravasation, and a large thick-walled arterial hæmatoma in connection with the severed ends of the artery.

External Iliac.—Four cases are included in Series II. In one, primary ligature was effected for a wound close to the origin of the deep epigastric artery. The patient did well.

In the second, an arterio-venous aneurysm developed secondarily to a wound by a revolver bullet. This patient was transferred to England.

In the third, the wound proved to be of the common femoral. A distal ligature was also applied. The femoral vein was normal and not ligatured. A good recovery ensued.

In the fourth case, a diffuse swelling of small size just below Poupart's ligament was noted during an operation for the closure of five perforations in the jejunum and ileum. Sixteen days later a blowing systolic murmur of greatest intensity above Poupart's ligament was noted. Local pulsation was present in the hæmatoma which gradually subsided and the bruit disappeared. A spontaneous cure was assumed. The patient was transferred to England and has not been further traced.

A fifth remarkable case was recorded by Captain Fry, (*Case 9*), to which reference has already been made.

It is noteworthy that in four of these five cases the lower third of the artery was the site of the lesion. It is probable that when the upper segments of the vessel are wounded and a breach made in the peritoneum, death from intraperitoneal hæmorrhage is rapid.

Certain difficulties occur in the diagnosis of these injuries ; thus, when the injury is close to Poupart's ligament, careful determination of the course taken by the missile and auscultation are useful in locating it to the iliac or common femoral.

The possibility of an aneurysm in the iliac fossa being really situated upon one of the branches of the main artery must also be remembered, before blocking the main trunk. A case was operated upon by Colonel Gunn, C.A.M.C., in which a diagnosis of aneurysm of the external iliac appeared manifestly correct, yet the operation showed it to spring from the root of the deep circumflex iliac, and the main vessel was spared.

In cases of aneurysm the transperitoneal route is the most convenient and suitable when the vessel requires to be dealt with.

When it is merely required to expose the vessel for provisional control, as for injuries to the common femoral artery, a vertical rectus-sheath incision, as for appendectomy, but with displacement of the peritoneum is preferable.

Several cases of ligature of the external iliac artery, for the treatment of injuries to the femoral vessels, are quoted below in connection with the latter.

Internal Iliac Artery.—One case of probable aneurysm, as diagnosed by auscultation, is included in Series II.

An operation was performed for the evacuation of septic blood clot from the abdominal cavity, secondary to a gunshot wound. A secondary hæmorrhage followed, and later a blowing systolic murmur was audible in the right iliac region, and conducted upwards to the aorta. A loud systolic murmur was audible at the cardiac apex, and diastolic shock was marked. This patient passed from observation.

More interest centres in the proximal ligature of this vessel or its posterior division in cases of gluteal hæmorrhage, as this seems the only instance in which proximal ligature at the seat of election has justified itself.

Cases recorded by Frost, Scott and McLachlan illustrate this point.

Wounds of the Great Veins of the Abdomen.

Some instructive examples of wounds of the inferior vena cava are preserved in the War Office Collection.

With a view to obtaining some idea of the frequency and fatality attendant on wounds of the vena cava and of the iliac veins, a number of recorded cases of abdominal gunshot injury has been examined.

H. W. Kaye met with two cases of wound of the inferior vena cava, and one of the right external iliac vein, in fifty-four post-mortem examinations made at a casualty clearing station. These cases were examined at an early stage in their histories.

Meyer and Taylor record no case of this injury among fifty operations performed. Stevenson Shaw and Mackenzie, among fifty operations, include one case of injury to the iliac vein, although the death of nineteen patients is ascribed to shock and hæmorrhage.

Crisp English records no case. Hughes and Rees, amongst one hundred and ten operations, record a case of wound of the epigastric artery and one case of retroperitoneal hæmorrhage; also one case of wound of the internal iliac artery, and one torn internal iliac vein.

Lockwood, Kennedy, Macfie and Charles, in a review of 500 abdominal gunshot wounds, with 356 operations, mention nine cases of non-visceral retroperitoneal hæmorrhage with 11·11 per cent. recoveries, and 23 of non-visceral intraperitoneal hæmorrhage, all of whom recovered. It is probable that in but few of these was a great trunk injured.

Sampson makes the following remarks. "It is surprising how frequently injury to the small intestine is complicated by injury to the iliac vessels or the vena cava. Large arteries either escape damage or more probably produce a fatal result before the patient can be moved. On the other hand, injury to the great veins is often found. This additional source of hæmorrhage has in my experience always led to a fatal result."

Cuthbert Wallace says the big vessels injured are the vena cava and the iliac veins. No case of wound of the abdominal aorta has been dealt with at an operation. His investigations on the influence of the position of the wound track on the viscera shed some light on this subject, since he comments on the rarity of mid-line wounds above the umbilicus, and suggests that implications of the great vessels explain the non-appearance of patients with wounds of this region in the hospitals.

Sampson sutured a wound in the vena cava on one occasion without success, and D. C. Taylor records two operations in which wounds of the vena cava were present.

Case 12.—Operated on twelve hours after reception of the wound. Patient pale, with marked abdominal pain, tenderness, and rigidity. No vomiting; pulse, 100; respiration, 28. The liver and stomach were wounded, the aperture of entry of the piece of shell was over the tenth rib in the right posterior axillary line.

A small retroperitoneal hæmorrhage on the right side of the base of the mesentery of the small gut was noted during the operation on the stomach. Eight hours afterwards the patient died, and at the autopsy an enormous retroperitoneal hæmorrhage was found to have developed, and an oval hole, about the size of a threepenny-piece, was discovered in the anterior surface of the vena cava, just below the entry of the right renal vein.

Case 13.—Admitted three and a half hours after being wounded by a fragment of a bomb, which entered the abdomen an inch to the right and half an inch above the umbilicus. The patient was pale; pulse, 120; abdomen very rigid and tender; he had vomited four times.

At the operation much free blood was found in the peritoneal sac, the gastro-colic omentum was perforated, two veins bleeding, two tears in jejunum, and a small one in mesentery. The wounds were repaired by suture. Bleeding from the posterior abdominal wall continued, the intestines were packed back, and a hole in the posterior peritoneum was seen just outside the line of the vena cava, and a large hæmatoma. The peritoneum was slit up, and a large hole in the anterior wall of the vena cava, just below the entrance of the right renal vein. The tip of the finger was placed in the hole, a pair of artery forceps was applied to the cava above the wound, so as to plicate the wall of the vessel, and then a series of six pairs was applied, so as to close the wound effectually, and yet retain a viable, though reduced, channel. The omentum was packed around the forceps and the abdomen was closed.

On the fourth day the forceps were removed. No bleeding followed until the last pair was relaxed. This bleeding was trivial in amount, and readily controlled by gauze packings.

The plug was removed on the second day, the patient was transferred to England on the tenth day, and one month later he was said to be doing well.

A successful case of forcipressure of a wound of the portal vein was recorded by Romanis.

Hæmorrhage from the visceral vessels is the common cause of death in those gunshot wounds of the abdomen which come into the hands of the surgeon.*

The Carotid Arteries.

The two series include 128 cases of injury to the carotid vessels (Table I). The wounds of the soft parts were in almost every case of a minor character ; in this respect it will be noted that the proportion of bullet wounds is very high, and it may be added that when the missile was a fragment of shell or bomb it was usually small. In nearly half of the entire number the missile was retained.

TABLE I.

	Number.	Side of Body.			Missile.			Contusion or Spontaneous Thrombosis.	Primary Complications.			Secondary Hæmorrhage.	Cerebral Complications.	Aneurysm.		Result.	
		Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.		Fracture.	Nerve Injury.	Viscera of Neck.			Arterial.	Arterio-venous.	Recovery.	Death.
Series I	43	22	16	5	10	18	15	3	6	15	—	10	10	16	12	35	8
Series II	85	44	39	2	22	38	25	19	3	15	3	15	28	19	48	72	13
Totals ..	128	66	55	7	32	56	40	22	9	30	3	25	38	26	60	107	21

No reliable information can be obtained as to the number of men who succumb to primary hæmorrhage when these vessels are wounded. Certain significant facts, however, may be noted. First, that no large open wounds of the soft parts were met with in either series, the great majority consisting in narrow perforating tracks. Secondly, Makins, during a period of three years' duty as consulting surgeon, saw no patient in the hospitals on the lines of communication in whom the common carotid artery had been tied for the control of primary hæmorrhage.

Secondary hæmorrhage occurred in 25 instances or 19·5 per cent. of the whole number. In Series I it proved fatal in no fewer than six out of ten patients in whom it took place. This proportion is much larger than in Series II, the explanation being that in the latter an abnormal number of instances of

* See "Surgery of the War," Vol. I, Chapter XVII.

contusion and non-perforating injuries to the vessels are included. If the 66 perforating injuries be considered alone, the percentage occurrence is the same.

As would be expected from the nature of the wounds of the surrounding soft parts, a very large proportion of the injuries was followed by the development of some form of hæmatoma or traumatic aneurysm. This was so in 86 of 128 cases, giving a percentage of 67·1.

A considerable discrepancy occurs between the two series in the relative numbers of purely arterial and arterio-venous aneurysms. There is no doubt that the proportion shown in Series II is the more correct, and that the discrepancy depends almost entirely on the deficiency of exact information afforded by the official records. A less important element lies in the fact that arterial hæmatomata are commonly operated upon at an early stage. Series II contains a large proportion of such cases, in which the surgeon who made the notes did not see the patient until some time after the operation was performed. In any case the combined numbers do not err on the side of exaggeration in showing arterio-venous aneurysms of the common carotid to be twice as common as the purely arterial variety.

Spontaneous thrombosis and obliteration of the lumen of the artery occurred in about 20 cases ; in one instance an arterial aneurysm solidified spontaneously.

Complications.—The most important complication is fracture of the mandible, because it renders infection of the wound a likely event and thus favours the recurrence of secondary hæmorrhage. Four cases are included in Series I, and two of these were accompanied by secondary hæmorrhage. The question will be again referred to under the heading of treatment ; it obtains its chief importance in connection with the branches of the external carotid artery.

In two instances in Series I fractures of the skull complicated injuries to the carotid vessels and three instances occur in Series II. In four out of the five cases cerebral symptoms secondary to the carotid injury developed and some difficulty in diagnosis was caused. The combination is therefore one of some importance. The impaction of fragments of shells in the cervical vertebral centra, or fractures of the processes are not of much importance, except in the case of the vertebral artery.

The viscera of the neck were wounded in three cases in Series II. In two of these secondary hæmorrhage took the form of hæmoptysis consequent on wounds of the larynx and each proved fatal.

TABLE II.
Cerebral Complications in Traumatic Aneurysms of the Carotid.

No.	Date of Wound.	Position of Wound and Nature of Missile.	Local Pulsation, Thrill or Murmur.	Temporal Pulses : Indicating Thrombosis or Embolism.	Date of Onset.	Signs of Injury to Sympathetic.	Signs of Cerebral Disturbance.	Progress and Complications.
1	19. 5. 15	Small incised wound over left sterno-mastoid at level of angle of jaw. Fragment of shell.	Arterio-venous aneurysm of internal carotid.	Equal. ? Embolism.	Early.	Right pupil dilated, left palpebral fissure narrow.	Slight weakness right face, and tongue to right side. Motor system :—Upper extremity : L. normal ; R. no power of movement. Lower extremity : L. normal ; R. some tone, won't move on order, withdrawal on pricking sole. Sensory system :—Position : much loss right hand and arm. No further tests possible. Reflexes :—Arm-jerk : +. Knee-jerk : ++ ; R. > L. Ankle-jerk : +. Abd. : R. O ; L. +. Plantar : R. extensor ; L. flexor. Complete left hemiplegia.	No improvement.
2	18. 1. 16	Large wound posterior border of sterno-mastoid. Shell.	Arterio-venous hæmatoma, common carotid.	—	6th day.	None.	Complete left hemiplegia.	Anaerobic infection. Secondary hæmorrhage. Death. Improved after ligation of the carotid.
3	6. 7. 16	Entry 3 in. directly below left external auditory meatus. Shell.	Arterial hæmatoma, common carotid.	Left temporal pulse absent. ? Thrombosis.	—	Left pupil contracted.	Difficulty in articulation and swallowing.	The common carotid was tied proximally. Improvement followed in condition of arm, but none in face and tongue.
4	10. 5. 16	Oval slit 1 in. behind anterior margin of right sterno-mastoid, at level of thyroid cartilage.	Arterial aneurysm of common carotid.	Right temporal pulse absent. ? Thrombosis.	—	None.	—	—
5	—	—	Arterio-venous aneurysm of common carotid.	Equal. ? Embolism.	—	None.	Tongue protruded to right. Right facial paretic. Right upper extremity powerless. Some tone in right lower extremity, but could not move it to order.	—

TABLE III.
Cerebral Complications in Post-Operative Cases of Carotid Aneurysm.

No.	Date of Wound.	Position and Nature of Wound.	Local Pulsation, Thrill or Murmur.	Nature of Operation.	Date of Onset after Operation.	Signs of Injury to Sympathetic.	Signs of Cerebral Disturbance.	Progress and Complications.
1	1. 2. 16	Wound at upper border of thyroid cartilage; missile retained left side 4th intervertebral disc.	Arterio-venous aneurysm, common carotid.	Ligature of carotid in 4th week.	4th day.	—	Right hemiplegia and aphasia.	? Embolic. Death.
2	12. 1. 16	Through - and - through track from anterior border right sternomastoid to left sternoclavicular joint.	Arterio-venous aneurysm on one side, arterial on other side of neck, common carotid.	Insertion of Tuffier tube on 37th day.	62nd day.	—	Temporary loss of power in left arm. Headache. Vomiting.	Died from general toxæmia a few days later. ? Embolic.
3	23. 7. 16	—	Arterio-venous hæmatoma, common carotid.	Ligature of artery on 4th day, for extension.	Immediate.	—	Complete hemiplegia.	Died the night of operation. No naked-eye changes in brain.
4	16. 8. 16	Wound in posterior triangle; retained missile.	Arterio-venous aneurysm, common carotid.	Ligature on 18th day for secondary artery hæmorrhage.	Immediate.	None: but sympathetic irritation (sweating) on same side after operation.	Complete hemiplegia. Dull mentally. Limbs flaccid.	Much improved at end of three weeks. Some movement of leg.
5	16. 9. 16	Missile entered through mouth and was retained.	Arterial hæmatoma, common carotid.	Ligature on 4th day for secondary hæmorrhage.	Noted 3rd day.	None.	Complete hemiplegia with aphasia.	At end of 10th day aphasia gone and limb improving.
6	1. 9. 16	Fractured jaw.	—	Ligature of external carotid 8th day. Ligation common carotid 9th day for secondary hæmorrhage.	Immediate.	None.	Complete hemiplegia.	No improvement in three months.
7	—	Fractured jaw.	—	Ligature of internal carotid for secondary hæmorrhage.	Embolism. ? Date.	None.	Aphasia. Laryngeal paralysis.	Death. Clot in middle cerebral artery, softening, and hæmorrhage into internal capsule.
8	15. 5. 16	Small through - and - through track at level of upper border of thyroid cartilage.	Arterial hæmatoma.	Ligature of common carotid on 11th day.	Embolism 4th day.	None.	Complete left hemiplegia.	Little improvement.

TABLE IV.
Cerebral Complications in Cases of Minor Injury of the Carotid.

No.	Date of Injury.	Position of Wound and Nature of Missile.	Local Pulsation, Thrill or Murmur.	Temporal Pulses: Indicating Thrombosis or Embolism.	Date of Onset.	Signs of Injury to Sympathetic.	Signs of Cerebral Disturbance.	Progress and Complications.
1	16. 5. 15	Small slit near anterior border of sternomastoid 1 in. below angle of jaw. No exit wound. Shell.	Small circular area of induration. No abnormal pulsation. No murmur. Pulse 120 at first, fell to 84.	? Left > right.	—	No evidence.	Unconscious at first. Mental condition improved. Speech not bad. Difficulty in reading and writing. Motor system :—Right hemiplegia.	Died.
2	—	Entry wound middle of right sternomastoid on level with thyroid. Exit wound in anterior margin left trapezius 1 in. lower level.	No carotid pulsation. No murmur. Pulse 142.	Absent on left side.	—	Pupils, right > left. ? Sweating more left side of face.	Right face very weak. Motor system :—Upper and lower extremities : L. normal ; R. no power of movement ; slight rigidity of right limbs. Sensory system :—Reacts to pin-prick on both sides. Reflexes :—Arm-jerk : L. + ; R. O. Knee-jerk : R. > L. Ankle-jerk : R. > L. Abd. : L. + ; R. O. Plantar : L. flexor : R. extensor.	—
3	12. 12. 15	Wound back of side of neck over trapezius opposite sixth cervical vertebra. Missile retained or escaped by mouth.	No swelling or pulsation. No murmur.	? Diminished on left side.	—	Pupils, right > left. Slight ptosis.	Motor aphasia. Weakness of right face. Tongue deviates to left. Motor system :—Weakness right upper extremity. Some rigidity at elbow.	Aphasia and paralysis improved.
4	18. 12. 15	Entry right side of neck middle of anterior border of sternomastoid. Retained fragment of shell. (Left scalp wound.)	No pulsation or thrill. No murmur.	Equal on the two sides.	—	Left pupil > right.	No mental change. Motor system :—Upper and lower extremities : L. no power of movement ; R. normal.	Rigidity in left arm after three days' interval, which increased with a great deal of pain.
5	—	Entry anterior border of sternomastoid right side 1 in. above sternum. Retained over spines of 6th and 7th dorsal vertebra. Bullet.	No pulsation or thrill. No murmur.	Equal on the two sides.	—	No evidence.	Dull and stupid. Motor system :—Upper extremity : L. no power of movement ; R. brachial monoplegia. Paraplegia paralysis of bladder and rectum.	No improvement took place. Transferred to England.
6	21. 5. 16	Entry and exit small, over left carotid. Left scalp wound ; trephined ; nil found. Bomb.	Soft systolic bruit. No conduction.	Equal on the two sides.	—	No evidence.	Aphasic. Quite conscious. Motor system :—Upper and lower extremities : L. normal ; R. no power of movement.	Improved after ligation of carotid for secondary hemorrhage.

TABLE IV—*cont.*
Cerebral Complications in Cases of Minor Injury of the Carotid—cont.

No.	Date of Injury.	Position of Wound and Nature of Missile.	Local Pulsation, Thrill or Murmur.	Temporal Pulses : Indicating Thrombosis or Embolism.	Date of Onset.	Signs of Injury to Sympathetic.	Signs of Cerebral Disturbance.	Progress and Complications.
7	4. 1. 16	Entry centre of anterior border of left sterno-mastoid. Exit just in front of angle of jaw, right side. Bullet.	No pulsation or thrill. No murmur.	Left temporal pulse absent.	—	Pupils, left > right.	Mental condition normal. Motor system :—Upper extremity : L. normal ; R. forearm paralyzed and biceps and triceps slightly lower extremity : L. and R. normal. drowsy. Motor aphasia. Right side of face weak. Motor system :—Upper extremity : L. normal ; R. flaccid, distal movement very weak. Lower extremity : L. and R. normal.	Went home nearly well.
8	3. 1. 16	Entry wound just in posterior margin of middle of left sterno-mastoid. Shell.	No pulsation or thrill. No murmur.	Equal on the two sides.	—	Pupils, right > left. Left palpebral fissure narrow. Left side of face more flushed.	Dull and drowsy. Motor aphasia. Right side of face weak. Motor system :—Upper extremity : L. normal ; R. flaccid, distal movement very weak. Lower extremity : L. and R. normal.	Went home considerably improved. Right arm better. Speech better.
9	24. 1. 16	Entry 1 in. to right of 4th cervical spine. Exit 1 in. outside right angle of mouth. Bullet.	No pulsation, thrill or murmur.	Equal on the two sides.	—	Left pupil > right. Right face more flushed.	Left face paralyzed (supra-nuclear). Motor system :—Upper extremity : L. rigid and completely paralyzed ; R. normal. Lower extremity : L. rigid, slight voluntary movement at hip only ; R. normal. Sensory system :—Entire loss left side. Reflexes :—All increased left side. Plantar reflex extensor on left side.	—
10	27. 7. 16	Irregular gaping wound about 1 in. long immediately in front of tragus. Shell — (retained).	No pulsation, thrill or murmur.	Right temporal pulse absent.	—	No evidence.	Incomplete peripheral facial palsy right and slight upper neurone paresis left side. Motor system :—Upper extremity : L. flaccid and toneless, some power ; R. normal. Lower extremity : L. movements weaker than right side ; R. normal. Sensation diminished on left side. Reflexes diminished. Plantar reflex extensor on left side.	—

TABLE IV—cont.
Cerebral Complications in Cases of Minor Injury of the Carotid—cont.

No.	Date of Injury.	Position of Wound and Nature of Missile.	Local Pulsation, Thrill or Murmur.	Temporal Pulses: indicating Thrombosis or Embolism.	Date of Onset.	Signs of Injury to Sympathetic.	Signs of Cerebral Disturbance.	Progress and Complications.
11	25. 9. 16	Entry left side of chin. Exit posterior triangle.	Swelling left side of neck. No pulsation or murmur.	Equal on the two sides.	26. 9. 16, drowsy; 28. 9. 16, excited, hemiplegic and aphasic.	Pupils equal and contracted.	Right hemiplegia. Aphasia. Facial paralysis. Incontinence of urine and faeces.	Slight improvement on transfer. Not continued. 17. 10. 16, Slight right facial paralysis. Right hemiplegia. Very slight movement of right leg. Knee-jerks: ++. Ankleclonus. Thick speech. Lingual paralysis. Muddles words. Incontinence improved. Right arm total paralysis. 1. 10. 17, Facial paralysis, slight. Can flex right arm; no extensor power. Fingers contracted but can be straightened. Can flex thigh, knee and ankle. Foot stiff and inverted. Knee and ankle-clonus. Died 5th day.
12	6. 4. 17	Small entry wound over thyroid cartilage in mid-line.	No tumour, pulsation or bruit.	Equal on the two sides.	Immediate (?)	Pupils equal and reacted.	Right hemiplegia.	Died 4th day.
13	20. 2. 17	Small entry wound at left angle of mandible. Exit below right mastoid process.	No tumour or pulsation.	—	3rd day.	—	Complete left hemiplegia.	Died 4th day.
14	30. 1. 17	Centre of right cheek. Right pinna. Right mastoid process.	No tumour or pulsation.	—	Drowsy immediately. 2nd or 3rd day.	—	Coma. Signs of compression.	Died 2nd day.
15	13. 7. 16	Entry at junction of right ala nasi with cheek.	No tumour or pulsation.	—	—	—	Right hemiplegia. Coma.	Died 3rd day.

The most common nerve complications are lesions of the cervical sympathetic. Signs were present in six instances in Series I, and in nine instances in Series II (roughly 12 per cent.). In some cases improvement followed, and in some the signs were of irritation rather than of paresis.

It is not possible to form any reliable estimate of the frequency with which the trunk of the vagus is injured, because no signs develop to indicate its involvement. Abductor laryngeal paralysis is almost as common as signs of injury to the sympathetic (9 per cent.). It is certainly more common in injuries to the lower half of the common carotid artery, and then is naturally referred to the recurrent laryngeal branch, but it is possible that in some of the cases the parent trunk is really the injured part.

Of the nerves in less intimate relation injuries to the hypoglossal, the facial, the spinal accessory, and to the nerves of the cervical and brachial plexuses were met with in the two series.

Injuries to the latter may be of diagnostic interest when they are present together with cerebral complications.

Cerebral complications must be divided into two categories, namely, those that directly follow the injury and those secondary to ligature of the vessels. It is obvious that in the first the cerebral anæmia follows obstruction to the blood-stream by thrombosis or embolism. The former accident must be regarded as the more serious, since beyond the occurrence of a local obstruction it may extend into the whole length of the middle cerebral and its branches, while an embolus may only obstruct one or more of the branches and thus give rise to an area of anæmia not only more limited in extent, but also possessing the advantages dependent on the existence of a collateral circulation.

Local obstruction due to ligature of the artery gives rise to a pure anæmia uncomplicated by any lesion of the cerebral vessels; hence it may be of a more evanescent nature and may disappear with the rise in the general blood-pressure leaving no serious consequences behind it. Some further remarks on this subject will be found under the heading of treatment.

There is no divergence as to the frequency of occurrence of cerebral complications in the two series, and among the whole 128 cases they were met with 38 times (29·6 per cent); namely, seven times in connection with aneurysms or hæmatomata, 11 times after ligature of the artery and 20 times in connection with thrombosis following partial injury to the artery.

Two important qualifications must be borne in mind in the consideration of these figures. First, not a single case of primary ligature of the artery is included in either series since no material exists from which to obtain information ; secondly, the number of minor injuries is large in Series II in consequence of the consulting surgeon concerned being especially interested in these cases.

The mode of onset of symptoms after ligature of the common carotid artery is fairly constant. As a rule the cerebral symptoms are either immediate or noticed in the course of a few hours. When, after the application of a proximal ligature, the distal segment of the vessel is left in communication with the sac of an aneurysm, the detachment of an embolus may take place after a few days, or even at a more remote period. Nos. 7 and 8 in Table III were two such cases.

When the cerebral symptoms follow thrombosis of the artery, it is far more difficult to say when they are likely to develop. In some of the cases recorded above they were immediate and the course of events is identical with that seen after occlusion of the vessel by ligature. In other instances the symptoms were delayed, and then it seemed reasonable to assume that the thrombosis was of the extending variety. This conclusion, however, is open to much doubt, since an extensive thrombus may form without any apparent ill result ; thus, the internal carotid artery in the neck has been seen to be blocked throughout during the course of an operation for ligature of the common carotid, and yet no signs existed at the time or developed afterwards. When the symptoms first become apparent at a later date, it seems reasonable to assume the lodgment of an embolus ; but here again the mere question of date is of little use and a certain diagnosis is more likely to be made when the paralysis is incomplete by a careful



Fig. 8.—Contusion and minimal wound of common carotid. Thrombosis of internal carotid, extending into cerebral vessels. The minute perforations are indicated by the two dark spots at the upper part of the carotid trunk.

consideration of the focal signs present as a means of locating the position of the embolus.

The general lines upon which a diagnosis should be based have already been mentioned, but it is nevertheless necessary to emphasize the fact that it is easy to mistake signs due to a purely vascular disturbance for those of compression resulting from injury to the brain, or intracranial hæmorrhage. Two of the cases included illustrate this point. In a third a



Fig. 9.—Thrombosis of right sylvian artery in connection with a wound of the common carotid artery.

trephine opening had been made ; and in a fourth bilateral symptoms, in conjunction with the presence of a scalp wound on the opposite side of the head, suggested a combination of contusion of the brain and possibly hæmorrhage on one side with vascular disturbance on the other. The existence of an optic disc in the early stage of papillitis, so commonly seen in conjunction with the œdema of the brain occurring in the early stage of cerebral injuries, might prove a useful diagnostic point since simple obstruction of the carotid causes little or no obvious retinal change.

Reference to Tables II, III and IV, gives some idea of the gravity of cerebral complications in vascular disturbance, but it must be remembered that the series of cases there recorded are all of a severe type. All except four who died within a few hours were observed in general hospitals on the lines of communication, that is, some days after the reception of the injury. This fact tends to show that, while on the one hand fatalities may be even more numerous than is shown here, yet time enough had elapsed for patients with evanescent symptoms to have got over their troubles without the real nature of the signs having been discovered. It is well known that the pareses and even paralyses which may follow ligature of the common carotid artery are sometimes very transient, sometimes persistent, sometimes followed by a fatal issue; and there can be little doubt that the similar conditions due to vascular disturbance from thrombosis or embolism may follow the same course. It is also known that thrombosis of the carotids may give rise to no symptoms whatever; further, that when paralysis does occur, the patients are either unconscious of it, or unwilling to recognize it. Hence the assumption is justified that the proportion of patients in whom the symptoms are transient or slight is far greater than the series under consideration would suggest.

The material furnished may be shortly summarized as follows:—

(1) Amongst 14 cases in which the common carotid artery was ligatured for the treatment of secondary hæmorrhage, hemiplegia developed in three (21·4 per cent.); in one of these death occurred within twenty-four hours, in one the hemiplegia and aphasia improved, and in one it was persistent.

(2) In 13 cases in which the operation was undertaken for the early treatment of either arterial or arterio-venous hæmatomata, hemiplegia developed in five instances (38·4 per cent.). In one patient the paresis was transient; in one partial recovery ensued; in one the paralysis persisted with little improvement, and in two death resulted. One death took place within twenty-four hours; the second was not directly the result of the arterial injury or of its treatment, the patient dying of general infection from multiple wounds, and the paralysis was transient and of the upper extremity only.

(3) These two short series combined give a total of 27 cases of ligature of the common carotid, in eight of which (29·6 per cent.) cerebral complications ensued, and three of the patients succumbed—two as a direct consequence of the

operation. Only one of these eight patients made a complete recovery.

(4) The prognosis in the 15 cases of cerebral complications consequent on minor injuries to the vessels, followed either by thrombosis, or thrombosis and embolism, is still more grave; but in this instance it must be recognized that there is complete ignorance regarding both the number of such injuries in which traumatic thrombosis had led to no evil effect whatever, and perhaps the still larger number in which transient phenomena had been present, the real significance of which was not appreciated.

(5) Amongst the 15 cases, death occurred in five (33·3 per cent.) during the first four days. Only one instance of transient paresis and complete recovery was observed. In the remaining fourteen patients, although improvement occurred in six, all were discharged from the army as permanently unfit, and probably none are ever likely to be able to follow any active work.

One remarkable observation was made in two of the three cases under consideration, ligature of the common carotid artery being apparently followed by a distinct improvement in the symptoms.*

Simple proximal ligature was performed in 33 cases, usually at the most convenient spot in relation to the wound of the vessel, and only occasionally at the seat of election.

Table V shows the general result to have been cure in 54·3 per cent., relief in 33·3 per cent., death in 12·1 per cent., and that cerebral complications followed in 33·6 per cent.

TABLE V.

Cases of Proximal Ligature for Wounds of the Carotid.

	No.	Cured.	Re- lieved.	Died.	Cerebral Complication.	
Series I.	16	8	6	2	3 {	1 temporary 1 fatal
Series II.	17	10	5	2	9	2 fatal
Total	33	18	11	4	12	Died, 3

* Short abstracts of these cases will be found in Sir George Makins' "Gunshot Injuries to the Blood Vessels," pp. 140 *et seq.*

TABLE VI.

Indications for Proximal Ligature.

	Secondary Hæmorrhage.					Arterial Aneurysm.					Arterio-venous Aneurysm.					Precautionary.				
	No.	C.	R.	D.	C.C.	No.	C.	R.	D.	C.C.	No.	C.	R.	D.	C.C.	No.	C.	R.	D.	C.C.
Series I...	9	4	3	2	3	3	3	-	-	-	4	1	3	-	-	-	-	-	-	-
Series II...	11	7	3	1	6	4	2	1	1	2	1	-	1	-	-	1	1	-	-	-
Total ..	20	11	6	3	9	7	5	1	1	2	5	1	4	-	-	1	1	-	-	-

C=Cured. R=Relieved. D=Died. CC=Cerebral Complication.

As would be expected, the worst results were obtained in the cases of secondary hæmorrhage. All three deaths followed recurrent hæmorrhage, and in one case cerebral complication was also present. In all these cases infection played a part, while the lowered arterial pressure due to the loss of blood would make cerebral complication likely.

A more instructive deduction may be drawn from a brief analysis of the consequences of employing this method in cases of hæmatoma or traumatic aneurysm. In one arterial aneurysm embolism from the sac occurred on the fifth day, causing persistent hemiplegia. In a second it is stated only that the aneurysm diminished in size. A third died with cerebral complication of purely anæmic character.

Of five arterio-venous aneurysms, only one was cured. In one, cerebral embolism occurred on the sixth day, in one the aneurysm diminished in size, and in two it is definitely stated that the thrill and murmur due to the arterio-venous communication persisted.

Although it is known that such persisting communications may close at a later date, yet the whole series shows the danger of escape of clot from the sac when the distal channel is left open, and also the inefficacy of the method in obtaining an immediate cure.

In two instances the innominate artery was ligatured as a secondary measure for the control of recurring secondary hæmorrhage after the common carotid artery had been ligatured. In each, death ensued in a few hours; in both the original operation had been performed in an infected wound.

Only two cases occur, both in Series II, in which an arterio-venous sac was definitely dissected out. Both these patients recovered without any complication. In some of the cases included in Table VII the primary sac was wiped or stripped away, but such can scarcely be regarded as definite excisions needing careful dissection.

TABLE VII.

Ligature of Carotid above and below Wound.

	Number.	Cured.	Relieved.	Died.	Cerebral Complications.
Series I	15	9	2	4	2
Series II	12	11	—	1	—
Total	27	20	2	5	2

TABLE VIII.

Indications for Ligature above and below Wound.

	Secondary Hæmorrhage.					Arterial Aneurysm.					Arterio-venous Aneurysm.				
	No.	C.	R.	D.	C.C.	No.	C.	R.	D.	C.C.	No.	C.	R.	D.	C.C.
Series I	1	—	—	1	—	8	3	1	2	2	7	5	1	1	1
Series II	3	2	—	1	—	4	4	—	—	—	5	5	—	—	—
Total	4	2	—	2	—	10	7	1	2	2	12	10	1	1	1

The general results of ligature above and below the wound show a great improvement over proximal ligature in that 74 per cent. were cured, 7·4 per cent. relieved, 7·4 per cent. had cerebral complications, although there were 18·5 per cent. of deaths.

Of the five deaths, two died after secondary ligature of the innominate in infected wounds, one died of general infection, the patient being the subject of multiple wounds, and two of recurrent secondary hæmorrhage. The whole category, therefore, belongs to that of the treatment of suppurating wounds, and not to that of simple ligature of vessels.

It is difficult to determine in how many of this series the artery and vein were ligatured simultaneously, but this was certainly the case with the twelve arterio-venous lesions, the category which shows the best results both as to the non-occurrence of cerebral complications and low mortality. Out of the eleven cases which recovered, the aneurysm was cured in all, although one has to be entered as relieved only, in consequence of a cerebral complication.

Series I contains one case and Series II five cases of suture of the vessels. These may be shortly detailed as follows:—

Case 14: Arterio-venous Aneurysm.—Small shell wound on left side of neck. A moderate-sized aneurysm with typical signs.

The sternomastoid was divided and the aneurysm exposed, the major portion of the swelling being accounted for by the dilated jugular vein. Provisional ligatures were applied to the carotid above and below the aneurysm, and to the internal jugular vein. The sac was then opened and a long narrow slit in the carotid was exposed. The wounds in the artery and vein were sutured and the sac removed. This operation by Major Hope was the first one of suture of the carotid done during the war.

The patient made an uneventful recovery.

Case 15: Arterio-venous Aneurysm.—Shrapnel wound of right side of neck; missile retained at left side of first dorsal vertebra. An arterio-venous aneurysm formed, not apparently of large size, the signs being indistinguishable from those of a simple varix. There was right sympathetic paralysis.

Nine weeks after reception of the injury a type operation was performed as described above. It was found necessary to divide three-fourths of the width of the sternomastoid in order to deal satisfactorily with the lower end of the jugular vein, for the vessels were still somewhat fixed in consequence of primary infiltration of the vascular cleft with blood. The vein was large.

When the circulation had been controlled, the vein was opened, as no sign of a sac was to be seen from the front. An opening in the back of the vein was disclosed, communicating with a sac lying behind the vessels and in the substance of the prevertebral muscles. Both vessels were now mobilized, and the artery was found to have an oblique slit on its postero-internal aspect, and communicated by this opening with the sac lying behind the vessels. The arterial defect was closed by suture, and the opening in the vein sewn up from the interior of the vessel; lastly, the exploratory incision in the vein was closed, and the repair was completed. The sac was not removed.

Except for some anæsthetic sickness, an uninterrupted recovery followed, and, as far as can be judged, the vessels have remained patent. The sympathetic paralysis steadily improved.

Case 16: Arterio-venous Aneurysm of Left Internal Carotid Artery.—A piece of shrapnel case entered at the left angle of the mandible, and was retained opposite the disc between the third and fourth cervical vertebræ. An arterio-venous aneurysm formed, associated with left sympathetic paralysis. It was not possible to determine whether the internal or the external carotid was involved.

Six weeks later the aneurysm was explored; the sac proved to be a junction chamber interposed between the internal jugular vein and the lower end of the internal carotid artery. When the control ligatures had been tightened up, the sac was laid open, but fairly free bleeding took place, the blood apparently being furnished by the ascending pharyngeal and superior thyroid arteries, each of which needed to be freed and controlled by an arterial clamp. The opening in the vein was easily sewn up, but as the field of operation could not be kept free of blood on the arterial side, in place of removing the remains of the small sac, sutures were passed through it, and thus it was plicated and closed.

The future progress was uneventful, except that some enlargement was found to be present at the site of the sac when the patient had his wound dressed a week later. This enlargement was exaggerated by induration of the surrounding tissues, and over it a somewhat harsh systolic bruit, much increased in loudness by pressure of the stethoscope was heard.

The patient was up and about at the end of three weeks, and the local condition steadily improved. The plication of the sac, although it much facilitated the operation, was unsatisfactory.

Case 17: Arterio-venous Aneurysm.—A bullet wound was followed by prompt development of the aneurysm. The patient was only retained in France for a few days. He remained in hospital for some time, was then discharged, and led an easy life for more than a year. The main trouble experienced was the buzzing noise in the head and opposite ear. No active exertion had been made since the date of injury.

The signs were typical, with associated sympathetic paresis. At the end of fourteen months an exploration showed the sac to be small and interposed between the two vessels. The sac was incised, the wound in the vein sewn up, and the same course taken with the artery. Uninterrupted progress ended in complete recovery.

Case 18: Arterio-venous Aneurysm.—A fragment of shrapnel case entered just behind the anterior border of the sternomastoid of the left side, and lodged against the vertebræ on the left side of the mid-line. A typical arterio-venous hæmatoma resulted. It was soft and rather extensive, with indefinite margins. Twelve days later it was explored. No definite sac had formed, but the hæmatoma was sufficiently well localized to allow the provisional ligatures to be applied without any great difficulty. When the vessels were exposed, a perforation was seen on the antero-external aspect of the upper third of the common carotid artery, and a laceration of the vein. Troublesome bleeding from the vein necessitated double ligature of that vessel. The artery was mobilized, not without some difficulty, on account of the induration of the areolar tissue of the vascular cleft. The visible defect in the wall was then sutured, and the blood allowed to enter the vessel from above. This act was followed by free hæmorrhage from the back of the vessel. The upper provisional ligature was again tightened, and on examination a second oblique slit in the posterior aspect of the vessel, which had been closed by adhesion to the prevertebral fascia, was found to have been reopened in the process of mobilization of the vessel. This second slit was repaired with some difficulty and the wound closed. The patient made an uninterrupted recovery.

Case 19: Arterio-venous Aneurysm. Failure to cure Varix.—Bullet wound of neck. Typical minimal wounds of entry and exit, bullet passing from behind the centre of the left sternomastoid to emerge near the mid-line at the level of the cricoid. A typical arterio-venous aneurysm developed at the level of the cricoid cartilage, the sac extending towards the mid-line.

Three months later an operation was undertaken. The soft parts had in great measure regained their normal state, and little difficulty was experienced in defining the sac, which lay to the inner side of the artery. As it was considered that a direct communication was present between the internal jugular and the artery, the vein was opened as a preliminary procedure. No opening was found. The artery was then mobilized, and separated from the sac, with which it communicated by an elongated slit on its inner aspect. When the interior of the artery was inspected from this opening, a small opening on the opposite side filled with clot was seen. A probe would not enter this aperture, and it appeared to be the blocked origin of a superior thyroid branch placed in an abnormal position. The operation was then completed, but, as a very long slit had been made in the jugular vein, the provisional ligatures were made definite, and the intervening portion of vein was excised.

Three days afterwards the patient complained of an attack of pain in the neck, and the dressings were removed. Examination showed that the

arterio-venous bruit had returned, and the veins at the root of the neck pulsated freely. No evidence existed during the next three months of recurrence of the arterial sac, but the bruit persisted, although the pulsation of the veins at the root of the neck diminished in force. The patient declined any further intervention, and returned to Canada.

A Tuffier's tube was employed in one case in Series I by Colonel Gordon Watson. The tube became obstructed during the first twenty-four hours, but no cerebral disturbance was noted, in spite of the fact that an arterio-venous aneurysm was present on the opposite side of the neck. The patient died a month later from general infection. The site of the tube was occupied by a solid column of connective tissue of the same calibre as the artery of which it joined the two ends.

Mortality.—The average mortality of 21 deaths in 128 cases (16·4 per cent.) is probably a fair one for injuries to the carotid vessels which reach the hospitals on the lines of communication or the base. It must be borne in mind that the whole number of deaths from primary hæmorrhage is excluded from these series, and that while no material is forthcoming to fill this gap, reasons have already been given which suggest that death occurs in almost every case in which a perforating injury to the carotid is exposed in an open wound.

The causes of death in the whole series were as follows :—

Secondary hæmorrhage	..	..	..	..	..	9
Cerebral complication	..	..	..	..	..	5
General septic infection	..	..	..	..	..	1
Compression of trachea	..	..	..	..	..	1
Gas gangrene	..	..	..	..	..	1
Spinal meningitis	..	..	..	..	..	2
Concurrent injury to head	..	..	..	..	..	1
Chloroform poisoning	..	..	..	..	..	1

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Treatment.—The following rules for the treatment of injuries to the carotid vessels may be deduced from the foregoing material.

Except in cases of emergency, proximal ligature of the common carotid artery is to be avoided. The method entails risk of secondary hæmorrhage and the occurrence of embolism ; further it may fail to cure an aneurysm, and in the case of arterio-venous lesions it is at the best only likely to be followed by obliteration of the opening of communication after a long interval.

All wounds or recent hæmatomata should be treated by ligature of the artery immediately above and below the opening.

In cases of aneurysm of mature development, the sac of the aneurysm may be at the same time excised if this is readily practicable. The method ensures the leaving of the smallest amount of cicatricial tissue liable to cause trouble from adhesion of structures or involvement of nerves.

In cases of arterio-venous aneurysm both the carotid and jugular have as a rule been ligatured. This procedure has not been observed to exert any deleterious influence; on the contrary, results have been uniformly good.

Evidence is forthcoming to show that ligature of both artery and vein should be the rule whether the latter be injured or not.

In the two series the results are as follows in 51 cases :—

TABLE IX.

	Ligature of Artery alone.	Ligature of Artery and Vein.	Cerebral Complications.
Series I.	18	9	8
Series II.	13	11	3
Total	31	20	11

When a well-localized hæmatoma, either arterial or arterio-venous, has formed, and no evidence of extension or enlargement exists, operation should be deferred in order to allow for improvement in the local condition of the tissues and compensatory changes in the circulation. Six weeks' delay is advisable, and in the case of the well developed aneurysm, three to six months. Arterial aneurysms are the more dangerous and likely to need prompt treatment; in arterio-venous aneurysms the longer the delay the easier the operative treatment becomes.

Suture of the vessels is the ideal procedure. It is easier in the neck than elsewhere, but it is not advisable when more than one-third of the circumference of the vessel has been destroyed, unless it is practicable to resect the injured portion and make an end-to-end union. The application of flaps of vein wall or other tissue is not a good procedure, as it tends to favour subsequent contraction.

The adoption of plastic methods with the use of portions of the aneurysmal sac to make up defects is bad. Thrombosis

is likely to follow, while, if not, the tissue is no substitute for arterial wall and is liable to stretch, and thus a recurrent aneurysm develops.

No instance is recorded in either series of the adoption of distal ligature, but one successful case has been published by Lawford Knaggs. The operation was undertaken on the grounds "that the communication between the sac and the artery is usually quite small, and the aneurysm a well-marked saccular one. The aneurysms occur in young soldiers in whom the arteries are healthy, a factor of some importance, for there is less danger of enlargement of the communication. Local conditions, therefore, are eminently favourable to consolidation of such tumors if only the blood-stream can be sufficiently slowed and weakened." The following is the record of this case.

Case 20: Traumatic Aneurysm at the Root of the Neck. Distal Ligature of the Common Carotid.—The patient was 19 years of age. Twelve weeks after reception of the wound a small ovoid pulsating swelling was present, pressing forward the lower portion of the sternomastoid and presenting behind the posterior border of the muscle. The pulsation was expansive and a sharp, harsh bruit was audible over the tumour. The swelling was increasing in size, and in view of the fact that the wound must be close to the bifurcation of the innominate artery, it was decided to ligature the common carotid above the omo-hyoid. Four days later the sac was smaller, gave a feeling of greater solidity, and the bruit was less marked. Pulsation continued. Twenty-three days after the operation no visible pulsation existed, palpation suggested transmitted pulsation only, and the patient had become unconscious of the beating which worried him before. Three months later recovery was apparently complete.

Bearing in mind the grave nature of the operations on the vessels at the root of the neck, this experience is valuable in suitable cases.

One case of injury to both common carotid arteries is included in Series II. The patient eventually died of general systemic infection, but without cerebral trouble.

One case of ligature of both common carotids at an interval of forty-three days has been reported by Major Cornelius A. Griffiths. The operations were performed to control secondary hæmorrhage from the base of the skull, possibly emanating from the internal carotid within the skull or from the cavernous sinus. The patient recovered without any evidence of cerebral disturbance.

General Prognosis.—In injuries of the carotid artery cerebral anæmia and its results take the place of the peripheral gangrene which occurs in injuries to other blood-vessels. The following factors which may influence its occurrence were recognized from the experience gained in the war :—

A low blood-pressure, due to hæmorrhage or shock, or a combination of the two conditions; reduction of the total volume of blood in circulation; a condition of general septic infection; an active or compensatory vaso-contraction; possibly a condition, which has been termed "vascular stupor" by Veau, Viannay, Lacoste, and Ferrier, secondary to contusion of the parent trunk.

Consideration of these possible factors should lead to the observance of the following precautions in dealing with injuries to the carotid vessels.

Operations whenever possible should be deferred during the persistence of shock, or of a low blood-pressure due to recent hæmorrhage.

The rapid escape of the diminished quantity of blood supplied to the vessels of the brain should be opposed by obstructing the jugular vein prior to dealing with the artery.

The blood-pressure should be raised if necessary by transfusion of blood, or by infusion of hypertonic or gum saline solution.

The force of gravity should be utilized in favouring the blood supply of the brain, by raising the foot of the patient's bed.

It will be noted that all the arterio-venous lesions have been classed under the heading of aneurysm. This has been necessary on account of the incomplete nature of the notes, but there is good reason to assume that a third of the cases more nearly approximated the condition of aneurysmal varix. It should also be noted that the small number of operations for arterio-venous lesions recorded in Series II is due to the fact that the majority were in no need of early operation and hence were transferred from the lines of communication to the United Kingdom and it has not been possible to trace them further.

Consideration of this series of cases appears to warrant the assertion that apart from the risk of cerebral disturbance, injuries and ligature of the carotid arteries leave no serious sequelæ. Experience shows that men who have suffered these injuries may resume their normal occupation without any obvious disability. It is also clear that an aneurysmal varix may persist without occasioning any trouble beyond that which may result from the murmur being audible to the patient.

Injuries to Branches of the Carotid Arteries.

The records give little special information regarding the external and internal carotids. As to the external carotid,

twelve cases are included, of which one died from secondary hæmorrhage, in one a typical arterio-venous aneurysm developed, in four the common carotid was tied, and in four cases the common, external and internal carotids were ligatured for wounds in the neighbourhood of the bifurcation. All four patients were cured. In one case of injury to the external carotid near the bifurcation, an extending thrombus completely blocked the internal carotid and gave rise to cerebral symptoms and death.

The main experience gained as to the external carotid was the ample corroboration of the danger attendant on proximal ligature of the trunk when hæmorrhage is actually coming from a wound of one of the branches. This subject is fully discussed by Harold Burrows and Kazanjian dealing with a series of 34 cases of secondary hæmorrhage where the external carotid artery was ligatured for hæmorrhage from its branches ten times with an attendant mortality of 50 per cent.

Eleven cases of injury to the internal carotid are included in the series. In one the vessel was seen to be thrombosed during an operation upon the external carotid; in this instance no cerebral disturbance was noticed. In a second the common carotid and the internal carotid were tied for hæmorrhage from a leaking aneurysm connected with the commencement of the internal carotid, and the operation was a success with no complication. In a third the common carotid was tied for an arterio-venous aneurysm of the internal carotid. No cerebral disturbance followed but the actual result on the aneurysm is doubtful; it is only stated that the wound healed well, and the "tumour diminished in size." In a fourth all three carotids were tied for an aneurysm at the bifurcation, and the patient made a recovery without any impairment of power. In a fifth case contusion of the artery was followed by thrombosis and cerebral complications.

The main interest of these cases lies in the proof that obliteration of the internal carotid does not necessarily give rise to cerebral disturbance, nor did such disturbance follow in four cases, in which the three carotid vessels were tied and thus the help of the collateral circulation by passage from the external to the internal carotid was abolished. This experience raises the question whether the formation of an anastomosis between the internal and external carotid trunks, when the common carotid is tied close to the bifurcation, is worth the extra trouble and prolongation of the operation.

Wounds led to the formation of aneurysms upon the occipital,

facial and temporal arteries as well as upon the superior and inferior thyroid arteries. The wound of the superior thyroid led to the development of a pulsating swelling within the sheath of the thyroid gland which was mistaken for a carotid aneurysm. The patient died from secondary hæmorrhage; blood welled up from the fossa pyramidalis which was traversed, passed down into the air passages, and a fatal hæmoptysis followed. The wound of the inferior thyroid was followed by the development of an arterio-venous aneurysm which was also thought to be carotid. Secondary hæmorrhage called for intervention, when the wounded vessel proved to be the inferior thyroid.

The Subclavian Arteries.

Records of injuries to the subclavian artery are few. The comparative rarity depends partly on the dangerous nature of the injury, partly on the short course run by the trunk in a somewhat sheltered position.

TABLE X.

	Number.	Side of Body.			Missile.			Contusion or Spontaneous Thrombosis.	Primary Complications.			Secondary Hæmorrhage.	Gangrene.	Amputation.	Aneurysm.		Result.	
		Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.		Fracture.	Nerve Injury.	Chest.				Arterial.	Arterio-venous.	Recovery.	Death.
Series I.	17	10	5	2	5	8	4	—	2	7	1	2	1	—	4	6	14	3
Series II.	28	16	12	—	15	9	4	2	3	7	10	2	3	—	13	11	22	6
Totals	45	26	17	2	20	17	8	2	5	14	11	4	4		17	17	36	9

In only four of the cases included in the two series (Table X) was there a large open wound; of the remainder, the very great majority were narrow tracks, nearly half of them caused by bullets. In about ten of the whole number there was a considerable primary hæmorrhage, but the notes are very defective as to this particular. In three cases secondary hæmorrhage was the indication for operative intervention, and two of these patients died; in both the latter the original wound was an extensive open one.

In two instances the wound was followed by spontaneous thrombosis, and in one of them an embolus was detached and blocked the bifurcation of the brachial artery, causing gangrene of the hand. In three instances the vessel was completely divided, and in one of these the lesion, which had been unattended by primary hæmorrhage, was discovered only at an early exploration of a divided brachial plexus.

The actual nature of the lesion in the remaining cases was not recorded. It is of interest to note that in three instances it was discovered, during an operation for arterial hæmatoma, that the vein had been wounded, even severed, without the formation of an arterio-venous anastomosis, no doubt as a consequence of the wide interval which separates these two vessels in the first and second portions of their course.

A traumatic aneurysm developed in connection with the injury in thirty-four of the forty-five cases. In seventeen of these the aneurysm was purely arterial, and it is of interest to note that in one instance an arterio-venous bruit, present in the early stages, disappeared after a few weeks, and at the operation only the artery needed to be dealt with. Sixteen cases were definitely noted as arterio-venous aneurysms and one as an aneurysmal varix. The general tendency is for aneurysms in this position to be moderate in size or small. On several occasions they were only discovered at a comparatively late date, and in the case of the varices the thrill and murmur are the safest and most useful diagnostic signs.

Absence of the peripheral pulse at the wrist is a comparatively common sign in injuries of the subclavian artery; it is definitely noted in twelve cases. This is probably explained by the fact that the artery is so situated between the clavicle and first rib as to be readily influenced by pressure from effused blood. If a local bruit disappears together with the pulse, it may be assumed that thrombosis has occurred at the wounded spot. Great difficulty may exist in locating an injury at the root of the neck to the correct vessel; careful auscultation and, in the case of arterio-venous injuries, observation of the system of veins to which pulsation or thrill is communicated are the most useful signs upon which to rely.

No material discrepancy exists in the two series as to the relative frequency of arterial and arterio-venous lesions respectively. It is true that a larger proportion of arterial hæmatomata is shown in Series II, but it must be remembered that many of the cases in this series were seen earlier, and that the arterial variety more frequently demands prompt intervention.

Complications.—A considerable discrepancy is seen between the two series in the association of wounds of the chest with those of the subclavian artery. This is probably explicable from the fact that the cases in Series II were seen early and before the patients had been segregated, and again the consulting surgeon concerned was in a position to see and examine any serious chest case.

Hæmothorax is recorded in eleven of the forty-five cases—seven times on the right, four times on the left side of the body. All the patients recovered, one in spite of infection and consequent empyema which needed drainage. In only three of the patients did a well-marked aneurysmal tumour form in the neck. It appears probable that if the subclavian artery be the source of the blood of the hæmothorax, the blood primarily escapes into the pleural sac as the direction of least resistance, and hence a large primary cavity in the neck is not formed. It may be added that late detection of aneurysms has been more common in this region than elsewhere.

Fracture of the clavicle was present in five instances, and is of considerable importance as increasing the difficulty of operative procedures, especially in dealing with the subclavian vein.

One or more cords of the brachial plexus were implicated in fourteen out of the forty-five cases. In four of these, the second portion of the artery was the seat of the wound, in nine the third portion. The combination of peripheral nerves affected varied, but the posterior cord suffered most frequently. It will be noted that associated injuries to the brachial nerves occurred in about the same degree of frequency in the axillary series. Information as to the ultimate results is, unfortunately, very defective, but such evidence as is available suggests that these are considerably better in the case of the subclavian. This view is in accordance with what the anatomical relations would lead us to expect, since they are less intimate than those of the axillary vessels and nerves.

Prognosis and Treatment.—No material is available from which to determine the mortality from primary hæmorrhage.

In the cases under review, the facts that no fewer than 16 cases with aneurysm were transferred to the United Kingdom and have not been traced further, and that a further six in Series I either were judged unfit for operation or refused treatment, render it difficult to form a fair opinion of what the results of operation in subclavian aneurysm really are.

Such records of operations as are available are far from encouraging, and there can be no doubt that the risks are very great on account of the technical difficulties which attend the procedure.

Eleven cases of proximal ligation of the artery are included in the two series, two of the first part, one of the second part and six of the third part. Two of the patients died, one from exhaustion after secondary hæmorrhage, and one from the effects of hæmorrhage from an arterio-venous aneurysm while still on the operating table. Of the nine recoveries, one with an open wound died three months later of secondary hæmorrhage, systemic infection and exhaustion. In two instances the procedure failed to cure the aneurysm; in one of these consolidation was procured later by distal ligation of the third part of the axillary artery, and in the second the aneurysm was successfully excised. In the remaining six cases at any rate a local cure may be claimed.

In two cases the artery was ligatured above and below an aneurysm, one patient was cured and one died the same evening as the result of hæmorrhage during the operation superadded to anæmia due to primary bleeding.

In two cases the aneurysm was excised, in each case successfully, but one of the patients lost the tips of his fingers from gangrene.

Two operations, one for suture and one for excision, ended fatally from the entry of air into the veins during the operation. In each of these fatalities the wound in the vein was adherent to a fracture of the clavicle.

Two operations for secondary hæmorrhage failed. The wounds were plugged, but the patients died shortly afterwards.

Owing to the importance of these injuries a short précis of some of the cases subjected to operation is of value. Three of the cases Nos. 25, 28 and 31, are not included in Series I and Series II.

Case 21: Arterial Aneurysm of the Second Portion of the Subclavian Artery.—Bullet wound; narrow non-infected track. Seen on third day. Complete right brachial monoplegia. Soft pulsating swelling with pure systolic bruit extending from clavicle to upper margin of thyroid cartilage. No radial pulse. Patient pale and anæmic. On the fourteenth day the aneurysm appeared larger and softer. An angular incision was made, a temporary clamp placed on the innominate artery, and the second portion of the subclavian artery, which was completely severed, was ligatured. A well-defined sac had formed, and hæmorrhage from this was very free, in spite of the clamp on the innominate artery. The original hæmatoma had become divided into two parts, one superficial, which was occupied by greenish fluid bounded by decolorized layers of lymph; one deeper, which formed the actual aneurysmal sac. Much blood was lost during the operation, and the patient died in the evening.

Case 22: Arterial Hæmatoma of Left Subclavian Artery.—Bullet wound. Operation on twentieth day. Extending arterial hæmatoma filling left posterior triangle. Proximal ligature of first portion of artery. The man was transferred to England eighteen days after operation with the aneurysm still active. The wound became infected, and the patient died from septic infection and exhaustion three months after the original injury.

Case 23: Arterial Hæmatoma of First Part of Right Subclavian Artery. Embolism of Brachial Artery. Gangrene of Hand.—Bullet wound. A tumour with a systolic bruit formed; on the eighth day incipient gangrene of the hand and forearm was noted. The hæmatoma increased gradually, and on the twentieth day a proximal ligature was placed with great difficulty on the root of the first portion of the vessel. The clot was infected. Patient died shortly after the operation.

Case 24: Arterial Hæmatoma of Third Portion of the Subclavian Artery. Local Ligature of the Vessel. Gangrene of Forearm and Hand.—Bullet wound. An arterial hæmatoma formed, gradually increasing in size. On the tenth day the vessels were exposed, both artery and vein were injured at the point of junction with the axillary, and were ligatured on either side of the opening. On the twelfth day the hand became blue, and general malaise pointed to septic absorption. On the thirteenth day the arm was amputated in the lower third. The patient recovered.

Case 25: Traumatic Aneurysm of Second Portion of Left Subclavian Artery.—Bullet wound. Injury to circumflex nerve. At the end of three months pulsating tumour in posterior triangle. The aneurysm was exposed three weeks later, and a ligature applied to the base of the sac as it sprang from the convex aspect of the artery.

Pulsation recurred, and twenty-five days after the first operation the clavicle was divided and reflected centrally, the anterior scalene muscle divided close to its origin, and the artery ligatured at the junction of its first and second portions. A good recovery was made and the aneurysm cured.

Case 26: Arterial Hæmatoma of Left Subclavian Artery, Third Portion.—Bullet wound. Operation on twenty-sixth day for extending hæmatoma. The artery was wounded in more than one place, and was approached through the hæmatoma. Difficulty was experienced in applying the ligatures, and the patient died upon the operating table.

Case 27: Arterio-venous Aneurysm of Right Subclavian Artery and Vein. Proximal Ligature.—Shell wound. At the end of six weeks a typical arterio-venous aneurysm was treated by ligature of the first portion of the subclavian artery. Fourteen days later a recurrent murmur was noted, and the man was discharged from the service as permanently unfit three and a half months after reception of the injury.

Case 28: Arterio-venous Hæmatoma of Right Subclavian Artery and Vein. Excision of Sac and Second and Third Parts of the Artery.—Bullet wound. Brachial monoplegia, aneurysm occupying posterior triangle. A fortnight (?) after the injury the clavicle was resected, ligatures were placed upon the first part of the subclavian and the commencement of the axillary arteries, and the sac together with the intervening portion of the vessel removed. The subclavian vein was ligatured. The wound suppurated on the tenth day, and the portion of resected clavicle had to be removed subsequently. On the twelfth day secondary hæmorrhage occurred, and during the next week six further hæmorrhages, on each occasion controlled by plugging. Anæmia called for saline infusion on one occasion. A second ligature was now applied, $\frac{1}{2}$ in. from its origin, to the first part of the subclavian artery. The patient recovered, but with persistence of paralysis of all the muscles of the limb, except those of shoulder and the flexors of the forearm.

Case 29: Arterio-venous Aneurysm at Junction of Second and Third Parts of Right Subclavian Artery.—Bullet wound. A typical arterio-venous tumour was exposed by division of the origin of the sternomastoid from the clavicle,

and division of half the width of the anterior scalene muscle. Provisional ligatures were applied to the first and third portions of the subclavian artery and to the distal vein. The vein was adherent to a perforation of the clavicle, and, while this was being separated, air entered the proximal end of the vein and the patient suddenly expired.

Case 30: Arterio-venous Aneurysm of the First part of the Subclavian Artery.—Small shell wound. A sac developed, extending upwards in the line of the common carotid artery. On the seventy-fifth day the sac was exposed by an angular incision, with division of the lower end of the sternomastoid muscle. The sac was punctured during the process of freeing it in the neck, but the opening was readily controlled while a ligature was being applied to the innominate artery. The sac was in great part removed, and the communication with the vein closed by a ligature thrown around it. Temporary paralysis, due to cerebral anæmia, was noted on the evening of the second day after operation and persisted for two days, when it commenced to pass away. A good recovery was made.

Case 31: Removal of a Fragment of Shell from the Subclavian Artery.—A patient admitted a few days after receiving a punctured wound half an inch below the centre of the clavicle, accompanied by musculo-spiral paralysis. The wound was leaking, and on the second day after admission a severe hæmorrhage took place. Exploration of the wound showed the origin of the hæmorrhage to be an injury to the second portion of the subclavian artery. The patient received a saline infusion, and the artery was exposed; a piece of shell could be felt within the lumen of the vessel, and partially blocking the opening in the wall. The artery was ligatured and the missile, which "appeared to have acted as a partial ball valve," was removed. A good recovery was made.

Localized gangrene occurred once in the cases of Series I, the tips of the fingers being lost after excision of an aneurysm. Three instances occurred in Series II, in each of these it resulted from embolism at the bifurcation of the brachial artery. This proportion of embolism seems large, but it may be pointed out that the detection of an embolus in the brachial artery is comparatively easy, and it may well be that more cases of gangrene in the lower extremity occur than can be determined from clinical examination.

Only two cases of injury to the first part of the subclavian on the left side are included in the series. In both a hæmothorax resulted. One patient recovered in spite of the fact that infection necessitated drainage of the pleural sac, and that gangrene, due to a brachial embolism, was treated by amputation through the lower third of the arm. The second patient died from secondary hæmorrhage after an incision made for pleural drainage.

In considering the advisability of operations on the subclavian artery the following points should be taken into consideration.

A leaking subclavian artery in an open wound should always be dealt with radically at the primary examination. It is more readily identified at this stage than at any other.

The practice of plugging wounds in the posterior triangle is almost always unsatisfactory ; secondary operations are difficult, and in consequence are usually followed by disaster.

Operations for the treatment of traumatic aneurysm of the subclavian artery are always serious. They are open to special risks in the difficulty often experienced in controlling hæmorrhage, and in the facility with which air may be aspirated into the veins should they be wounded.

The individual characteristics of every case should be considered, bearing in mind that the general tendency of arterial aneurysms is towards increase in size, but that the absence of abnormally dilated veins makes the operative procedure less difficult ; that the sac of arterio-venous aneurysms tends to decrease in size, and hence there is rarely need to interfere before the tissues have reached a favourable condition for identification and dissection of structures ; that cases in which the vein is adherent to a fractured clavicle offer special risks and difficulty ; that in operations for arterio-venous aneurysms a provisional proximal ligature of the subclavian or innominate vein should be an early step in procedure ; and that provisional proximal ligature of the innominate artery decreases the amount of bleeding, but does not arrest it. Hence care is required in opening the sac of the aneurysm.

Exposure must be free, hence a long incision is required when the third portion of the artery is to be approached.

When the first or second portion is to be approached, the incision from the sterno-clavicular joint along two-thirds of the length of the clavicle should be prolonged from the inner end upwards for nearly half the length of the anterior border of the sternomastoid. Division of the sternal head of the sternomastoid or of its whole width one inch above its insertion and, if needful, division of the anterior scalene muscle with due care of the phrenic nerve commonly give ample room for dealing with the innominate or any part of the subclavian artery.

Division of the clavicle increases the severity and risk of the operation. It is rarely needed except for reaching the innominate vein in special cases, or when the junction of the subclavian and axillary arteries is the point to be ligatured.

There is reason to believe that the ultimate results of ligature of the subclavian artery are better than those of the axillary, because accompanying nerve lesions tend to be less severe. Two of the patients included in Series I returned to light duty. The large majority were discharged as permanently unfit for military service.

Injuries to Branches of the Subclavian Artery.

Three cases of injury to the vertebral artery were met with in Series II. In two no operation was performed, as the patients appeared to suffer no disability. In each the softness of the systolic bruit was relied upon for diagnosis, together with absence of sign of injury to either the carotid or subclavian arteries. In one of them a fracture of the transverse process of the seventh cervical vertebra supported the diagnosis. In the third case, the sac lay in the sub-occipital triangle. It was exposed by dissection, and as it was found impracticable to apply ligatures locally it was opened and plugged provisionally. The artery was then ligatured at the root of the neck, and the aneurysm was cured.

One case, included in Series I, was admitted to hospital as an aneurysm of the lower part of the common carotid artery.

Case 32.—A large curved incision was made along the anterior border of the sternomastoid, and carried outwards along the clavicle. The sternomastoid was divided, and the common carotid exposed and found to be uninjured. A portion of the internal jugular vein was excised, and a sac, springing from the vertebral artery, and passing onwards beneath the scalenus anticus, was exposed. The sac was cleared and excised, and some difficulty was met with in ligaturing the upper end of the artery. The wound healed, but signs of sympathetic pupillary paralysis persisted. The patient was discharged to furlough seven weeks later.

The case is quoted as illustrating the best method of dealing with a vertebral aneurysm at the root of the neck. It would not always be necessary to excise the jugular vein.

One instance of an aneurysm on the inferior thyroid is mentioned in the section on carotid aneurysms; Series I contains a case of aneurysm on the thyroid axis. Both were diagnosed as carotid aneurysms. The thyroid axis case terminated fatally from the aspiration of air into a wounded vein during the operation commenced for the cure of the aneurysm.

CHAPTER VIII.

INJURIES TO THE VESSELS OF THE EXTREMITIES.

The Axillary Artery.

THE wounds of the soft parts in the neighbourhood of the axillary artery were not extensive or of the most severe class, as might be assumed from the comparatively large proportion in which the missile was a rifle bullet. It is probable that when this vessel is lacerated in large open wounds few of the patients survive to reach the hospitals. The customary want of information in respect of primary hæmorrhage is met with. In eight cases in Series II it is said to have been severe. In three cases in Series I and in one case in Series II the artery was ligatured early, possibly primarily.

The following table gives the details of the 108 cases recorded.

TABLE I.

	Number.	Side of Body.			Missile.			Contusion or Spontaneous Thrombosis.	Primary Complications.			Secondary Hæmorrhage.	Gangrene.	Amputation.	Aneurysm		Result.	
		Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.		Fracture.	Nerve Injury.	Chest.				Arterial.	Arterio-venous.	Recovery.	Death.
Series I	54	25	25	3	11	27	16	2	4	27	1	10	1	3	26	12	45	9
Series II	54	27	21	6	39	15	—	10	—	23	10	8	2	1	24	16	50	4
Totals	108	53	46	9	50	42	16	12	4	50	11	18	3	4	50	28	95	13

In Series II no less than ten instances are included in which spontaneous thrombosis and obliteration of the vessel took place. Two are recorded in Series I. The occurrence is probably more common than is supposed, as many of such patients passed at once into the category of nerve injuries. The arrangement of the nerve trunks around the vessel favours spontaneous arrest of hæmorrhage.

Secondary hæmorrhage is recorded in ten cases in Series I and in eight in Series II, on an average on the eleventh day with

extremes of three and 29 days. The third part of the subclavian was tied for this accident four times, with one death. The axillary was tied nine times with no fatality. One case died with no operative intervention; in two cases the wound was plugged, one of these underwent subsequent amputation and died. One case occurred secondarily to the use of a Tuffier's tube; the axillary artery was tied, but the patient died.

In 78 instances some form of aneurysm developed; there is some little discrepancy between the two series in this matter, the number of varices being greater in Series II, and the arterio-venous variety is rather more numerous. The striking particular in either series is the greater proportion of purely arterial aneurysms which result from the arrangement of the vessels and nerves of the axilla.

The commonest and most frequent complications are those due to the implication of the nerve trunks surrounding the artery. In no fewer than 50 of the whole number more or less serious nerve lesions are recorded, and when the relation of the blood vessels to the nerves is borne in mind there is no doubt that the actual number of nerve injuries is under-estimated. The numbers afforded by the two series are practically equal. Various combinations are seen, the musculo-spiral and the median being the two nerves most commonly furnishing isolated injuries. The mode of formation of the median nerve, moreover, disposes it to suffer partial lesions from injury to one of the heads only. In at least 14 instances the musculo-spiral alone suffered. Isolated lesions of the median and the ulnar were also met with.

The second frequent complication is wound of the thorax. In Series II no fewer than ten cases of hæmothorax are included, and in Series I only one case, which probably results from the method of classification, as the same discrepancy between the two series occurs in the injuries to the subclavian artery.

The remaining complications were three fractures of the humerus, one fracture of the scapula, and a wound of the shoulder joint, all of which are noted in Series I.

The occurrence of secondary hæmorrhage has been already dealt with. Limited gangrene of the tips of the fingers and thumb occurred once in Series I. In Series II one patient lost the tips of the fingers after a primary proximal ligature of the third part of the subclavian artery; and in another an amputation was performed through the lower third of the arm, for gangrene extending to the forearm after a primary ligature of the third part of the axillary artery.

Amputation was performed in three instances in Series I. In one the artery was ligatured on the seventh day, and four weeks later a secondary hæmorrhage followed passive movements of the shoulder joint ; amputation was then performed. In the second the artery was ligatured on the fifth day for the treatment of a hæmatoma. Five days later the limb was removed on account of its unpromising condition. No mention of gangrene is made. In the third case a hæmatoma was opened and the artery tied, a plug being left in the cavity. Amputation was performed two days later, probably on account of general infection. The patient died of shock.

Death occurred in 13 instances, nine in Series I, and four in Series II. In six cases death followed operations for secondary hæmorrhage, and was due to loss of blood, combined in three instances with serious septic infection.

In the remaining seven cases the causes of death were :— incision and plugging of hæmatoma ; ligature of axillary artery ; secondary amputation for sepsis ; general infection from original wound ; shock and loss of blood, following operation for arterio-venous aneurysm ; heart failure after operation for arterial aneurysm ; and combined effect of loss of blood from primary wound and operation for aneurysm.

Methods of Treatment.—In 18 cases the third part of the subclavian was ligatured, with the results shown in the following table :

TABLE II.

	Number.	Indications for Operation.				Gangrene.	Result.	
		Hæmorrhage.		Aneurysm.			Recovered.	Died.
		Primary.	Secondary.	Arterial.	Arterio-venous.			
Series I	9	1	2	2	4*	—	7	2
Series II	9	1	2	3	3	1	9	—
Totals	18	2	4	5	7	1	16	2

* One following a bayonet wound.

A proximal ligature only was applied in 14 cases. In two cases in which the artery was ligatured primarily, both patients recovered. In four cases operated upon for secondary hæmorrhage, two recovered and two died. In one of the latter division of the clavicle was employed. In four cases in Series I proximal ligature was performed for the cure of arterio-venous aneurysms; unfortunately no reliable information is forthcoming as to the ultimate results, but no accidents are recorded.

In three cases in Series II proximal ligature succeeded in the treatment of arterial aneurysms, but in one instance a pool of blood remained in the site of the aneurysm for some weeks after the operation, and was only slowly absorbed.

In three cases of arterio-venous aneurysm in Series II, ligature of the third part of the subclavian was accompanied by ligature of the third part of the axillary artery. In one instance the operation was successful. The two other cases are worthy of special note. In one, when the sac was opened after the two ligatures had been applied, free bleeding occurred, which was successfully treated by plugging; in the second the arterio-venous anastomosis persisted. These results impress the propriety of placing the ligatures either at the point of injury or in very close proximity to the sac, and the necessity of ensuring that branches are not left patent to feed the sac.

Ligature of the artery above and below the wounded spot was performed in 52 instances.

TABLE III.

Ligatures above and below wound of the Axillary Artery.	Number of Operations.	Indications for Operation.				Gangrene.	Result.	
		Primary Hæmorrhage.	Secondary Hæmorrhage.	Arterial Aneurysm.	Arterio-venous Aneurysm.		Recovered.	Died.
Series I	35	5	5	18	6	-	31	4
Series II	17	4	3	7	3*	1	15	2
Totals ..	52	9	8	25	9	1	46	6

* One aneurysmal varix.

A single proximal ligature in close proximity to the sac was applied with success in one instance. Nine operations for primary hæmorrhage were all successful; in two instances both artery and vein were ligatured. Eight operations for secondary hæmorrhage were performed. Two patients died. Twenty-five operations were carried out for the treatment of arterial hæmatoma, or of aneurysms. Of these cases three died, two from hæmorrhage, and one from acute post-operative tetanus. One death is unaccounted for. Nine cases were operated upon for the treatment of arterio-venous aneurysms, all of which recovered.

In the only case in which gangrene (of the tip of the thumb and of the middle finger) occurred, the operation was for primary hæmorrhage, and the patient suffered greatly from early transport.

The artery and vein are stated to have been tied simultaneously in 14 of the cases, and no instance of gangrene or death occurred. In the majority of the remaining cases the artery alone was tied.

The striking feature of Table III is the large proportion of arterial aneurysms operated upon. This depends simply on the fact that these more frequently increase, leak or cause threatening symptoms, while the arterio-venous tend to localize and decrease in size. No doubt a number of the latter were operated upon at a later date, but on this point information is lacking.

With regard to treatment of the sac, it is clear that in a number of the cases the so-called aneurysm was in the hæmatoma stage, since in nine cases out of 27 in which the interval between the injury and the operation is recorded, the latter was undertaken within 14 days. The average interval was 29 days, with extremes of 112 and two days. In only three cases is the sac said to have been dissected out, but no doubt in many of the early operations the provisional wall of clot was wiped out. In two, the oozing sac was plugged; one did well, but in the second recurring hæmorrhage necessitated amputation of the limb. In two instances the subscapular artery required to be ligatured in addition, as it was feeding the sac by a separate aperture, and in one the long thoracic was treated in the same manner.

Series II includes three cases of excision, two of arterial aneurysms, and one of arterio-venous aneurysm, in which a well-developed sac was dissected out. All did well.

Four cases in Series II were treated by suture. One primary

suture was performed. Of two aneurysmal varices, in which the anastomotic opening was approached by an incision in the vein, one gave an ideal result, and in one thrombosis followed, but a good result was obtained.

In one arterial aneurysm with large defect in the arterial wall, the base of the aneurysmal sac was utilized to reconstruct the vessel. A good result followed, but the artery thrombosed.

The above results justify the following deductions being drawn as to the treatment of injuries to the axillary vessels.

- (1) In all cases the early treatment should consist of ligature of the vessel immediately above and below the wound.
- (2) Ligature of both artery and vein is devoid of danger, and preferable.
- (3) Proximal ligature of either the axillary or the third part of the subclavian is to be regarded as applicable only in cases of great emergency or difficulty.
- (4) Ligatures placed above and below the lesion except in close proximity to the sac often fail in their object as a consequence of the number of branches of the artery. Hence bleeding may not be controlled, nor an aneurysm cured.
- (5) Arterial hæmatomata or more fully developed aneurysms require early treatment. An arterio-venous hæmatoma or aneurysm may usually be given time.
- (6) Excision of the sac gives excellent results in either form of aneurysm in the fully developed stage.
- (7) Suture may attain ideal results in properly selected cases, and is the procedure to be aimed at in all.

General Prognosis.—The most striking discrepancy between the numbers in Series I and Series II is seen in the relative frequency of spontaneous thrombosis and obliteration of the artery. In Series I only one case was met with, while in Series II spontaneous obliteration was met with ten times. The explanation is simple and in no way invalidates the statement that spontaneous control of hæmorrhage from this artery is comparatively common. Such injuries in the great majority of instances pass into the hands of the neurologist in the absence of either hæmorrhage or aneurysm formation, hence they are classified under the heading of injuries to the nerves. The matter is one of more than mere numerical importance since the most useless limbs of all tend to be met with in such cases.

Series I thoroughly substantiates the opinion that had been already formed in Series II regarding the unfavourable prognosis as to the ultimate fate of the limb in injuries to the axillary vessels. Loss of blood is the most prominent factor even when the large number of patients who must have died from primary hæmorrhage is eliminated.

The results in the patients who recovered in Series I are extremely unsatisfactory. Among 36 patients, whose duration of stay in hospital it is possible to determine, the average length of time amounted to 22 weeks, with extremes of three weeks and 56 weeks. Of the 45 patients who recovered two lost the limb by amputation. Eleven were discharged as permanently unfit for service, in 21 no definite record is obtainable, and in only 13 does any likelihood of further service seem indicated. Of these 13, six are last recorded as sent to convalescent hospitals, five discharged on furlough, and two reported fit for light duty. It is possible that a certain proportion of the 21 in whom the final condition is unrecorded may have returned to light duty.

In Series II only one out of ten patients with spontaneous thrombosis following injury escaped concomitant nerve injury, and in this case the artery lay exposed in an open wound.

Of the remaining nine patients, five returned to England with persistent complete brachial monoplegia; of the others, one proved to have suffered division of the median, ulnar and musculo-spiral nerves; in one the musculo-cutaneous nerve was divided and the remaining nerve trunks were fixed by cicatricial tissue; in one the posterior cord and its branches were alone affected; and in one in whom general diminution of sensation and tingling were present, the radial pulse returned at an early date. It has not been possible to trace these patients further, but general experience does not warrant the expectation that any great improvement took place.

Amongst 22 patients, in whom combined arterial and nerve lesions were followed by the formation of aneurysms, the results seem little superior. Amongst those cases in which special record is made, in nine the radial pulse was abolished, in nine it was diminished in volume, and in one both radial and brachial pulsation was impalpable. In only one case of axillary varix was the blood pressure in the injured limb equal to that in the sound one, and in this instance the lesion was the result of a bayonet stab and not a gunshot injury. The nerve symptoms present were as follows: complete brachial monoplegia, seven; signs of injury to median

and ulnar nerves, three ; to median alone, three ; to ulnar alone, two ; to median, musculo-spiral and ulnar, one ; to musculo-spiral, musculo-cutaneous and ulnar, one ; general anæsthesia, one ; anæsthesia in the area supplied by seventh cervical root, one. Only one of these patients recovered sufficiently to return to active service. The majority of the remainder were discharged from the service as permanently unfit.

It is not only from the point of contemporaneous injury to the nerves in the axilla that the vascular injuries are liable to be followed by unsatisfactory results. From the purely vascular aspect also, obliteration of the artery is apt to be followed by imperfect recovery. It is rare not to observe a cold cyanotic hand after ligature of this artery, and this evidence of depressed vitality may persist for considerable periods of time. Some loss of volume in the muscles of the limb is also common, to the extent of one inch in the forearm and half an inch in the upper arm. It is always the terminal segments of the limb which suffer more severely.

Arterio-venous aneurysms and aneurysmal varices often give rise to little change during the period in which there is no interference with the modified arterial circulation. In the case of the aneurysms ultimate operation is necessary, but in that of the varices it is better avoided if possible. It has always been known that these conditions give rise to less serious signs of venous obstruction in the upper than in the lower extremity ; but observation of a large number of cases has shown that venous obstruction may develop more frequently than has been supposed. Cases have been seen exhibiting clinically the signs of pure varix, in which the condition of the peripheral veins called for operation ; in one of these a tendency to enlargement of the veins also existed in the uninjured limb, and there can be little doubt that personal idiosyncrasy in this respect is a matter that must not be overlooked.

It is possible that the importance of the nerve factor may be to some extent diminished in the future by improvement in the methods of the surgeon neurologist, but at the best the grave effect of coincident lesions of the vascular nervous supply to the limb cannot be altogether eliminated.

Branches of the Axillary Artery.

A wound of any branch may be the source of an axillary hæmatoma or aneurysm, but the subscapular branch possesses

a special significance. Two cases are included in the series in which the subscapular formed an additional feed to an axillary aneurysm, and two others in which the wound was an isolated one. The special characteristic of this injury is the tendency for the extravasation to spread along the line of the course of the vessel to the trunk. When, as in one of the included cases, an associated injury to the median and musculo-spiral nerves, and absence of the radial pulse due to pressure by the extravasated blood are met with, the difficulty of diagnosis is great. If there be any suspicion, a permanent ligature should not be applied to the parent trunk until the site of the wound in the artery has been localized.

Wounds of the posterior circumflex artery give rise to a characteristic sub-deltoid hæmatoma which may simulate an inflammatory condition in the earlier stages, when the general body temperature is high and the local heat raised.

The Brachial Artery.

Injuries to the brachial artery, as uncomplicated accidents, probably occupy the third or fourth place in frequency of occurrence. In making any definite statement, however, difficulties arise, as the brachial artery was often ligatured primarily as a part of the treatment of a serious injury to the soft parts and this element of the treatment not specially classified. The frequent implication of the vessel in wounds involving the humerus often leads to the inclusion of the injury amongst the fractures, and again the common association of wounds of the arm with injuries to the chest has resulted in the inclusion of such lesions in the latter series.

The following table gives the details of the cases recorded in Series I and II.

TABLE IV.

	Number.	Side of Body			Missile.			Contusion or Spontaneous Thrombosis.	Primary Complications.			Secondary Hæmorrhage.	Gangrene.	Amputation.	Aneurysm			Results.	
		Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.		Fracture.	Nerve Injury.	Chest Wound.				Arterial.	Arterio-venous.	Variety not Recorded.	Recovery.	Death.
Series I	107	68	76	66	56	24	57	8	33	33	2	40	2	6	40	17	—	153	4
Series II	43	20	15	8	21	70	2	5	4	10	—	6	6	—	12	1	9	43	—
Totals	200	88	91	24	77	64	59	13	37	46	2	55	8	6	61	18	9	196	4

Only a small proportion of the wounds in Series I was of a simple perforating character, many were severe and infection was common. In a large number complications were present. Of the fracture complications, the humerus was implicated in 17, radius in 5, ulna in 6, bones of the hand in 3, and in 1 case each the pelvis, the femur, and the tibia. In 5 cases the elbow joint was implicated, in 2 the chest cavity, and in 2 the abdominal cavity. The 36 concurrent injuries to nerves were as follows:—median 23, ulnar 7, musculo-spiral 6, brachial plexus 2.

The large proportion of injuries to the median nerve naturally depends on the close association of this nerve with the artery, and it may be noted that beyond the liability to simultaneous injury, the nerve frequently becomes implicated in the scar associated with wounds of the brachial vessels, and hence secondary involvement is common. Only two cases of gangrene of the limb after ligature of the vessel are included in Series I, and in neither was the median nerve injured, although co-existing lesions of this nerve and the brachial artery are of serious import in regard to this particular.

In seven cases the ulnar nerve was involved, and in six the musculo-spiral. With regard to the latter nerve it is noteworthy that in only one of the six cases was the humerus fractured. This fact supports the view that many cases of fractured humerus in which the artery was injured have escaped inclusion in this series.

In only two cases of the whole series is a co-existing wound of the chest noted, and bearing in mind the common association of lesion of the chest and upper extremity, another source of omission of injuries to the brachial artery from the records is indicated.

Course and Results.—Of the 157 cases of wound of the artery in Series I, spontaneous closure of the aperture followed in eight; in one of these gangrene of the limb supervened.

In 25 instances the artery was ligatured for primary or recurrent primary hæmorrhage; all the patients recovered, but in two the vessel had to be ligatured a second time on account of secondary hæmorrhage. In one instance the third portion of the axillary and third portion of the brachial were ligatured simultaneously with success, and in one the brachial was ligatured at two levels for separate wounds, also with success.

In 48 instances the artery was ligatured for the treatment of secondary hæmorrhage. This occurred on the average on the ninth day, with extremes of three days and 23 days. In five

of these patients secondary hæmorrhage recurred, in four an amputation was necessary, and in one patient death followed amputation. One patient died of severe secondary hæmorrhage before any operation could be performed.

In 66 cases traumatic aneurysms formed, 49 of which were purely arterial, the majority being operated upon during the arterial hæmatoma stage. In 17 the aneurysm was arteriovenous or an aneurysmal varix. These numbers support the opinion already expressed by Makins that the arrangement of these vessels is not such as to favour the development of arteriovenous aneurysms.

Gangrene followed the operation of ligature once, and in one instance it followed spontaneous obliteration of the vessel.

Four deaths occurred in the series, one after secondary hæmorrhage, the patient being found dead in bed, no operation being performed ; two after repeated hæmorrhages and amputation, and one from repeated hæmorrhages.

Methods of Treatment.—In eight cases hæmorrhage ceased spontaneously and no operation was performed, and in three cases of aneurysm surgical intervention was considered unnecessary. In a fourth case of aneurysm spontaneous consolidation took place.

Of the 144 patients operated upon, 89 were treated by simple ligatures placed as a rule on either side of the wound of the vessel. Three of these patients died as a result of infection and repeated secondary hæmorrhage. In one instance a secondary aneurysm formed in connection with the seat of ligature. In twelve patients recurring secondary hæmorrhage necessitated the renewed application of ligatures ; two of the deaths and also two of the amputations occurred in this series.

The 43 patients in Series II were treated by various methods. A simple proximal ligature was applied to the artery some distance above an aneurysm in three cases, once with success and twice with failure to cure the condition. In nine instances the third stage of the axillary artery was tied ; in one instance the third stage of the axillary and the third portion of the brachial, in one the brachial at two spots, in two the brachial, radial, and ulnar, and in one the brachial and ulnar. All these cases recovered without the loss of the limb.

It is specifically recorded in only four cases that both the artery and the veins were ligatured ; all recovered without accident.

In two cases ligatures were applied through two separate wounds above and below an aneurysm with success.

In eleven cases ligatures were applied to the vessels above and below, and an aneurysm was excised with success.

In two cases Matas' operation is said to have been performed successfully, and in two cases the sac of the aneurysm was obliterated by suture after ligature of the vessels above and below. No details are available as to the patency of the vessel in the former two cases.

In the following five instances wounds of the artery were closed by suture :—(1) A wound in the artery was sutured and the vein tied. (2) The opening in the arterial wall was sutured, the sac of the aneurysm being left. (3) The wound in the artery was sutured primarily. A secondary aneurysm developed later at the seat of suture, and was cured by ligature of the artery. (4) An end-to-end union was made on the ninth day, two-thirds of the calibre of the vessel being destroyed ; the man retained a radial pulse at the end of two months, but it was said to be diminished in size. (5) An arterio-venous aneurysm was excised, the radial artery tied, and the ulnar joined to the brachial. In the fourth case only is any information given regarding the result of these operations, but the patients all recovered without loss of the limb.

Six other cases of suture have been recorded by Makins—one of primary end-to-end union which gave way on the tenth day, and two secondary end-to-end unions in which patency was retained, but with lowered peripheral blood pressure (127-140 mm. Hg. and 80-107 in the non-operated and operated limbs respectively). Three cases of lateral suture were followed by one ideal result, obtained by Captain Greaves, the blood pressure in the two limbs remaining equal ; and two qualified failures in which thrombosis probably took place.

Speaking generally, the results obtained in Series I (death 2·54 per cent., amputation 3·8 per cent. and gangrene 1·27 per cent.) are not unsatisfactory considering the facts that most of the wounds were severe, a very large number infected, and that a considerable proportion of the patients were the subjects of multiple injuries.

In the 43 cases of Series II the occurrence of gangrene was much higher (13·9 per cent.), but, as has been explained, the series was that of a consulting surgeon called in to see men seriously ill. It must also be noted that no instances of gas gangrene are included in the larger series, these accidents having been classified under other headings.

The cases of arterial suture do not afford much information ;

only one successful case has been examined, at an interval after the operation, and that of only two months. A second case furnished an ideal early result; in three, or perhaps six, the result was not better than if the vessel had been ligatured, and in two cases the line of suture failed and secondary ligature was performed. In no case did any serious accident occur. The poor results are probably referable to the small calibre of the artery as compared with that of the carotid, the femoral or the axillary.

When the cases of ligature are examined from the point of view of the ultimate condition of the limb, the results are less satisfactory. Even when a first class result was obtained some loss of volume of the muscles was observed, and amongst the records of the 157 cases of Series I, an almost uniform record of the need of massage for limbs, the nutrition and function of which were lowered, is very striking. Such records as exist show that, of 91 patients, the average stay in hospital amounted to $15\frac{1}{2}$ weeks, against which must be stated that many had severe wounds, complications such as fracture or nerve injury, and often wounds of other parts of the body.

Of 70 patients whose actual destination was noted on discharge from hospital, 19 were discharged to light duty or home service, 15 went on furlough, presumably prior to joining their units, 14 were sent to convalescent hospitals and 22 were discharged from the service as permanently unfit. It may be added that the opportunity occurred of examining a few patients, in whom the brachial artery had been ligatured, who had returned to active duty in France, and no doubt many such instances occurred, although the available notes do not afford information on this point. It is obvious that a more correct description of the great majority of the 157 cases would be "severe wounds of the upper extremity," in which ligature of the brachial artery became necessary, and in which the arterial lesion was but one element.

Vessels of the Forearm.

Injuries to the vessels of the forearm were very numerous, but as in the case of the brachial vessels few of these have been classified as purely arterial lesions. Of 59 injuries so classified, in 31 the radial artery was implicated, in 22 the ulna, while in six the notes do not specify which artery was the source of hæmorrhage.

Twenty-five were injuries to the right forearm, 30 to the left forearm, and in four instances the side of the body is not recorded.

Eighteen of the wounds are stated to have been caused by bullets, and 23 by fragments of shells or bombs. In 18 instances the nature of the missile is not recorded.

Six of the wounds were simple perforations, ten were multiple, several were extensive or severe, and a large proportion were infected.

In 23 cases, a fracture of one or both bones of the forearm was present ; thus, radius 11, ulna 17, radius and ulna 5.

Co-existing injuries to nerves are noted as follows :—ulnar six, median two, posterior interosseous one.

In three instances, a wound of the chest was also present. The remark already made with regard to the inclusion of many cases of injury to the arm in the chest series applies equally well here as the thoracic was judged the more important injury.

Course and Results.—Of the 59 cases, 55 were treated by ligature of one or both the arteries of the forearm, or ligature of the brachial artery. Of the remaining cases, one was treated successfully by plugging, one by amputation for secondary hæmorrhage, one died after an exploratory operation, and one in whom no operation was performed succumbed to secondary hæmorrhage.

In 11 instances, the operation was to restrain primary hæmorrhage, from the radial in eight, from the ulnar in three. In three of the 11, a proximal ligature only was placed upon the brachial, with no accident.

In 24 cases, secondary hæmorrhage necessitated operation, on an average upon the tenth day with extremes of three and 54 days.

In 23 cases, some form of traumatic aneurysm followed the wounds ; the notes do not, in a single instance, allow any inference to be drawn as to whether the aneurysms or hæmatomata were other than of the purely arterial variety.

No case of gangrene is included, but it must be borne in mind that gas gangrene is not mentioned in a single instance. No doubt all such cases are included under other headings.

Amputation was resorted to thrice, once for secondary hæmorrhage, once for trophic changes following ligature of the brachial artery, and once for recurrent secondary hæmorrhage.

The two deaths were due to anæmia, following secondary hæmorrhage combined with toxæmia.

Methods of Treatment.—In 27 of the cases the arterial wounds were treated by ligatures applied above and below

the lesion.; in six instances for primary hæmorrhage, in 10 for secondary hæmorrhage, and in 11 for the treatment of arterial hæmatoma or traumatic aneurysm. In one instance in which both radial and ulnar arteries were tied primarily the arm was subsequently amputated for trophic changes in the forearm.

In nine cases, two of the ulnar and seven of the radial, traumatic aneurysms were excised and the artery ligatured above and below. All the results seem to have been fair except one in which muscular ischæmia was noted. One case of radial aneurysm noted as "small" was left untreated.

Proximal ligature was resorted to in one instance only, and then with success.

Ligature of the brachial artery was resorted to in 15 cases, for primary hæmorrhage on four occasions. One of the patients was discharged the service with persistent ulnar paralysis, two were discharged as permanently unfit at the end of six and nine months respectively as a consequence of wasted and contracted limbs. In nine cases the operation was performed to arrest secondary hæmorrhage from the forearm. In one of these the patient was discharged as permanently unfit—"wasting, no radial pulse"—at the end of three months. In one it was necessary to tie the radial artery the next day. One patient was invalidated for an injury to the leg. Regarding the remaining six no special record exists; the men were discharged to convalescent hospitals, furlough or light duty.

In one instance of wound of the brachial above the bifurcation together with wounds of the radial and ulnar, the wound in the brachial was closed by suture strengthened by a flap of vein, the radial artery was anastomosed to the brachial and the distal end of the ulnar tied. Secondary hæmorrhage followed and on the tenth day the brachial artery was ligatured. The man was returned to duty at the end of eight months.

These cases show that the arterial lesions formed but an element in a number of serious injuries. It is probable that not a single case was a simple injury to the vessel, hence from the subsequent condition of the limb no useful conclusion can be drawn. The series, however, does demonstrate the fact that ligature of the brachial artery should never be resorted to for treatment of wounds of the vessels of the forearm if this method can be avoided; both the evil effect on the limb and the risk of recurrent secondary hæmorrhage are demonstrated.

The Femoral Artery.

Table V gives the details of injuries to the femoral artery in the two series. The proportion of bullet wounds in Series I is remarkable, although the large number of aneurysms shows that many of the wounds were of the simple perforating track type.

TABLE V.

	Number.	Side of Body.			Missile.				Primary Complications.		Secondary Hæmorrhage.	Gangrene.	Amputation.	Aneurysm		Result.	
		Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.	Contusion or Spontaneous Thrombosis.	Fracture.	Nerve Injury.				Arterial.	Arterio-venous.	Recovery.	Death.
Series I	196	91	88	17	85	45	66	1	—	—	68	38	38	62	51	147	49
Series II	170	56	61	53	—	—	—	20	—	—	20	36	—	36	51	147	23
Totals	366	147	149	70	85	45	66	21	32	6	88	74	38	98	102	294	72

In this table an important discrepancy is to be noted under the heading of contusions; this is explicable by the fact that in Series II this type of injury was specially sought out and watched on account of its important bearing on the occurrence of secondary hæmorrhage, peripheral gangrene and on the late development of aneurysms. In seven of the 20 cases included in Series II it appeared probable that the injury was an actually perforating one, as a temporary local bruit was present. In the remaining 13 the thrombosed vessel was seen—in seven instances during the performance of operations, and in five it lay exposed in an open wound. In five of these cases secondary hæmorrhage occurred.

A large proportion of injuries to the superficial femoral artery is given in each series, and this accords with the greater length of this vessel. Thus of the 263 instances in which the level of the injury is recorded, 34 were lesions of the common, 213 lesions of the superficial, and 16 lesions of the deep femoral trunks.

Series I contains ten wounds of the deep femoral trunk, and there are six in Series II. It is probable that these numbers by no means correctly indicate the frequency of the lesion,

since hæmatomata connected with this artery, in consequence of their tendency to spread upwards into Scarpa's triangle, were often diagnosed as having their origin in a wound of the common femoral.



Fig. 1.—Femoral aneurysm incorporating the sartorius muscle.

The prognosis is particularly bad. Four of the ten cases in Series I died; three as a result of gangrene following ligation of the artery, and one of exhaustion. In all four the indication for ligation of the artery was secondary hæmorrhage. Of six cases in Series II, three died; two as a consequence of gangrene, one from secondary hæmorrhage and exhaustion.

Series II includes seven cases of wounds of the circumflex branches. Of these three died, but not directly as a result of the special location of the injury, two from infection existing prior to the operation.

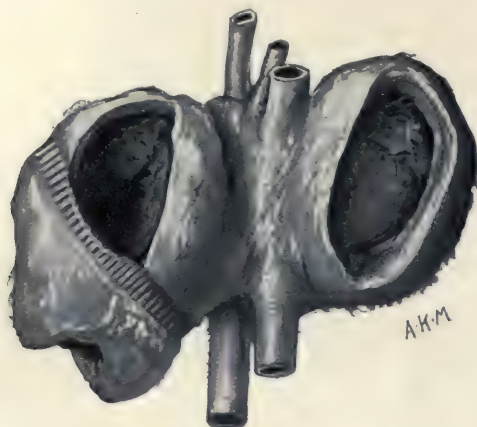


Fig. 2.—Bilateral false aneurysmal sacs in connection with the femoral artery.

Complications.—The character of the accompanying wounds of the soft parts varied greatly ; in many instances they were extensive, yet complications were not numerous. The most serious were fracture of the femur in 28—tibia and fibula, two ;



Fig. 3.—Arterio-venous aneurysm and aneurysmal varix. A sac has formed in connection with both the venous and arterial wounds on the free aspect of the vessels.

fibula, one ; patella, one ; wound of knee, one ; of ankle two ; trench foot, three ; injury to great sciatic nerve, four ; to anterior crural nerve, two. Many patients suffered from multiple wounds.

Secondary hæmorrhage occurred in 68 cases in Series I with 31 deaths, a mortality of 45·4 per cent. In Series II the proportion is smaller, but no material differences are observable as to the results. Table VI shows the results in all the cases in Series I that were treated by operation.



Fig. 4.—Femoral arterio-venous aneurysm. The dilated vein is laid open, and within are seen the termination of the profunda vein, and the arterio-venous channel. The aneurysmal sac is of the small typical form wedged into the angle between the two trunks.

Of the 31 deaths, 12 were from shock and anæmia after secondary amputations, and seven were from similar conditions after ligation of the arteries, three of the limbs having become gangrenous. Two patients died of pyæmia, two from systemic septic absorption. One patient died during an operation

for ligature. Three died from anæmia and exhaustion without an operation. Four died from recurring secondary hæmorrhage after ligature of the vessels.

Gangrene, occurring as a direct result of the injury to the vessels, was seen in seven cases in Series II, but only once in Series I. This may have depended on the inclusion of a larger number of patients suffering from trench foot, as such patients were less likely to be sent home early. The occurrence of gangrene as a result of ligature is dealt with below.

The proportion of cases of traumatic aneurysm is very large in both series, the slight discrepancy being influenced by the inclusion of the 20 cases of contusion of the vessels in Series II; otherwise the proportion is nearly equal in each series. The larger number of arterial, as distinct from arterio-venous, aneurysms seen in Series I is probably due to the fact that many surgeons deemed a simple diagnosis of "aneurysm" sufficiently explicit.

TABLE VI.

Results of Treatment for Secondary Hæmorrhage in cases of injury to the Femoral Artery.

Nature of the Operations.	No.	Gan- grene.	Amputa- tion.	Re- covered.	Died.
<i>Proximal Ligature.</i>					
External iliac	3	—	—	1	2
Common femoral	11	4	7	7	4
Superficial femoral ..	26	7	13	17	9
<i>Direct Ligature above and below.</i>					
Common and super- ficial	1	—	—	1	—
Common and profunda	1	1	—	—	1
Common, superficial, and profunda	1	—	—	—	1
Superficial	18	4	3	11	7
Abortive operation ..	1	—	—	—	1
Plugging	4	—	—	—	4
Amputation	2	—	—	—	2
Totals	68	16=23·5%	23=35·5%	37=54·4%	31=45·4%
Proximal ligature ..	40	11=27·5%	20=50%	25=63·5%	15=32·5%
Direct ligature ..	21	5=23·8%	3=14·3%	12=57·1%	9=42·8%

It has not proved practicable to determine from available records the proportionate occurrence of arterio-venous aneurysm

and aneurysmal varix. In Series I it is put down as nine amongst 51 cases, and the proportion is about the same in Series II. In fact, unless the lesion be exposed, it is difficult to be sure whether a sac is present or not, because the sacs are often very small and in these circumstances the main part of the tumour is formed by the dilated vein.

The most important point in Table VI is the larger mortality which followed double ligature at the site of the wound; this may have depended on the greater danger from loss of blood in the direct attack. Against this it must be noted that the proportionate occurrence of gangrene is higher after proximal ligature, and no less than 50 per cent. of the cases required secondary amputation.

In the cases of arterial hæmatoma and aneurysm recorded in Series I, Table V, seven deaths (11·4 per cent.) occurred. One death occurred after secondary hæmorrhage for which no operative treatment was undertaken, and one followed an amputation of the thigh. In one instance of recovery no operation is recorded.

In 58 of the cases operations were undertaken as shown in Table VII.

TABLE VII.
Operations for Arterial Aneurysm in injuries to the Femoral Artery.

Nature of the Operations.	No.	Gangrene of Limb.	Amputation.	Recovered.	Died.
<i>Proximal Ligature.</i>					
External iliac ..	2	2	—	2	—
Common femoral ..	2	2	—	2	—
Superficial femoral ..	16	1	3	13	3
<i>Direct Ligature above and below.</i>					
Common femoral ..	3	—	—	3	—
Superficial femoral ..	24	2	2	22	2
Superficial femoral and profunda ..	1	1	1	—	1
With excision of sac ..	9	—	—	9	—
With obliteration of sac	1	—	—	1	—
Totals ..	58	8	6	52	6

Little comment is necessary on these results. The operations were all performed within six weeks of the date of the original

injury, the majority during the hæmatoma stage. The deaths resulted from a combination of shock, hæmorrhage and systemic absorption in the presence of gangrene. No instance of secondary hæmorrhage from the site of ligature occurred and, as far as can be judged from the available notes, the aneurysm was cured in all the patients who recovered. It will be noted that the best results followed excision of the aneurysm, and ligature of the vessels directly above and below the site of the aneurysm. There is no doubt as to the superiority of these methods over that of proximal ligature.

TABLE VIII.

Results of treatment in Arterio-venous and Aneurysmal Varix in injuries to the Femoral Artery.

Operation.	Arterio-venous Aneurysm.						Aneurysmal Varix.					
	Number	Gangrene	Amputation	Failure	Recovered	Died	Number	Gangrene	Amputation	Failure	Recovered	Died.
<i>Ligature above and below.</i>												
Superficial femoral ..	14	3	3	1	8	6	3	-	-	-	3	-
Common, superficial and deep.	2	1	1	-	1	1	-	-	-	-	-	-
With excision of sac ..	7	-	-	-	7	-	-	-	-	-	-	-
Superficial femoral and popliteal.	1	-	-	-	1	-	-	-	-	-	-	-
Common and superficial	2	1	1	-	2	-	-	-	-	-	-	-
With suture of vein ..	1	-	-	1	1	-	-	-	-	-	-	-
Common, superficial deep and femoral vein.	1	-	-	-	1	-	-	-	-	-	-	-
<i>Proximal ligature.</i>												
Artery and vein ..	4	2	1	3	3	1	2	-	-	-	2*	-
Artery above and below, vein above.	1	-	-	-	1	-	-	-	-	1	-	-
Superficial femoral twice, then external iliac.	1	-	-	1	1	-	-	-	-	-	-	-
Profunda twice and femoral vein.	1	-	-	1	1	-	-	-	-	-	-	-
External iliac and superficial femoral.	1	-	-	1	1	-	-	-	-	-	-	-
Amputation	-	-	-	-	-	-	1	-	-	-	1	-
Digital compression ..	-	-	-	-	-	-	1	-	-	-	1	-
Totals .. .	36	7	6	8	28		7	-	-	1	7	-

* No details.

Series I contains 51 arterio-venous hæmatomata or aneurysms. Of these, eight were not subjected to operation.

Table VIII shows the methods of treatment adopted. Eight deaths are included, four from the combined effect of shock and hæmorrhage after secondary amputation, one from secondary hæmorrhage after amputation, two from systemic infection, and one probably from anaërobic gangrene and toxæmia.

In eight cases the operation undertaken failed to cure the condition, either from proximal ligatures only having been applied, or from the ligatures above and below having been placed too far from the site of the anastomosis. Gangrene supervened seven times : once anaërobic, six times anæmic ; in one of the latter gangrene of the toes preceded the operation.

It will be noted that seven of the 43 cases operated upon were of the nature of an aneurysmal varix. No accidents are reported in this small series, but the absence of details raises a doubt as to whether the two cases of aneurysmal varix treated by proximal ligature were cured.

Some of the cases of arterio-venous aneurysm were operated on at an early date. The results are less satisfactory than those of the arterial aneurysms.

The external iliac was ligatured primarily 10 times for the treatment of injuries to the vessels of the thigh. Seven recovered. Three of the cases were complicated by the presence of a fracture of the femur ; two of these patients died, one after a subsequent amputation for gangrene, performed on the fifth day, and one in consequence of the procedure failing to control the hæmorrhage from the thigh. Two of the operations were performed for uncomplicated wounds of the vessels ; in one both the external iliac and the common femoral were tied to restrain hæmorrhage starting during the removal of a piece of metal, and the patient recovered. In the second, an extensive infected open wound in Scarpa's triangle, gangrene supervened, and after an amputation on the fifth day death ensued. In two cases the artery was tied for arterial aneurysms ; one of the common femoral, one of the profunda ; in both consolidation of the aneurysm resulted, and both recovered. The three remaining operations were for the cure of arterio-venous aneurysm. In two the proximal ligature failed to effect a cure, and in one of them an additional distal ligature of the superficial femoral trunk was followed by no better result. In the third case the artery was doubly ligatured, but the wound suppurated, secondary hæmorrhage

took place, and the vessel was then tied successfully at a higher level.

The following case of aneurysmal varix, observed by Major B. W. Housman, in which an arterio-venous lesion was diagnosed on the grounds of "local pulsation and thrill," was treated by digital compression of the common femoral artery.

Case 1.—Continuous compression was maintained for one hour on the nineteenth day after the injury was received. "Pulsation was completely controlled in the femoral region, but faint pulsation persisted in the anterior tibial artery at the ankle. The foot became colder, but no further inconvenience was experienced."

Four days later compression was again exerted for one hour. "All pulsation and thrill then disappeared," and two days later it is noted "pulsation in the line of the artery only reappeared a few days after the cessation of compression."

After an interval of five days compression was again exerted for one hour. A week later the patient got up, more exercise was gradually allowed, and one month after the last application of compression the patient was transferred to an auxiliary hospital. "Beyond some thickening in the line of the femoral vessels, there was no difference in the condition of the two limbs."

It is a well-established fact that arterio-venous communications occasionally close spontaneously, hence the above case cannot be regarded too seriously. Nevertheless, it raises the important principle as to the possible favouring effect likely to follow a decrease in the local blood pressure at an early date after the establishment of an anastomosis. Sir Gilbert Barling, who saw the case in consultation and concurred in the diagnosis, says, "I saw the patient several times, and considered it worth while seeing what digital compression might do. The lesion was not in a convenient situation for operation, and I was anxious to do anything that offered a prospect of relief."

Of the 38 cases in which amputation was carried out, it was resorted to as a primary measure in seven instances; only two patients recovered. The five deaths all took place shortly after the operation; three patients had fractures of the femur, one of these died from pyæmia, but the wounds of all were infected. In the two other patients an aneurysm and secondary hæmorrhage were the indications respectively.

The remaining 31 amputations were secondary to operations on the arteries; in every instance death was due to the combination of shock, anæmia and septic infection. Many of the patients had large septic wounds, and in several a fracture of the femur was superadded to the flesh wound. One patient survived three weeks, four survived from two to five days, and the remainder died during the first twenty-four hours.

Amputation was in fact a last and desperate resource throughout. One of two cases of amputations at the hip joint survived.

Of the 196 cases in Series I, 180 were treated by ligature, as shown in the following table.

TABLE IX.

Arteries tied.	No.	Gan- grene.	Ampu- tation.	Re- covery.	Deaths.
External iliac	12	2	2	8	4
Common femoral	27	7	9	20	7
Superficial femoral	128	18	24	102	26
Hunter's canal	7	2	2	4	3
Deep femoral	6	2	1	3	3
Totals	180	31	38	137	43 23·8%

In 14 of the 196 cases there was no operation; one case was treated by suture and one by digital compression.

Very little information is available as to the results of primary ligature. In Series I only five cases are included; of these, three recovered without accident, in one gangrene necessitated amputation followed by recovery, and one patient died of recurrent hæmorrhage.

In Series II 45 cases treated by ligature are included. Two of the operations were followed by anaërobic gangrene, and one of the patients died. Anæmic gangrene followed in 11, or one-third of the whole number. In nine instances amputation was necessary, and two of the patients died. The incidence of gangrene and amputation is practically identical with that of Table IX, but the mortality is about 19 per cent. lower.

Table IX shows sufficiently the incidence of anæmic gangrene, and this condition was responsible for the great majority of the amputations performed. In but few cases did the gangrene extend beyond the lower third of the leg, and in many of the successful amputations it was confined to the toes of the foot. The very unsatisfactory results of amputation for this condition, when performed shortly after ligature of the main vessel, appear to indicate that an expectant attitude might at least be maintained for a longer period without increased danger, and possibly with advantage to the patient.

Perhaps the most striking feature in Table IX is the unsatisfactory nature of the results in wounds of the deep femoral artery, and after ligation of the superficial femoral in Hunter's canal. This feature is borne out by Series II in the case of the profunda.

Series I contains but a single instance of suture of the vessels. In this case a small wound was discovered in the superficial femoral artery during an operation for removal of a piece of metal. The wound in the vessel was "closed by suture; the tibial pulses were present next day." No further details are available, but the patient, the subject of a fractured femur, was discharged from the service as permanently unfit four months from the date of injury.

Series II contains nine operations, one upon the common femoral, and eight upon the superficial femoral artery; three of the operations were undertaken in the primary stage, three were intermediate, and three were remote.

The three primary operations afford little information, for two of them were of a complicated nature. In one the suture was of an arteriotomy wound which had been made for the evacuation of a thrombus following a contusion; recurrence of the thrombus ensued. The second illustrates the dangers to which a promising primary operation may be exposed. The patient arrived at a hospital on the lines of communication on the fifth day after suture of a lateral wound of the femoral artery, with an excellent posterior tibial pulse. Besides the wound of the thigh, multiple wounds of other parts of the body were present, and the patient succumbed after a few days to an acute general infection. The third case was a success; a lateral wound of the artery as it lies in Hunter's canal was closed by stitches, and the line of union strengthened by a flap of tissues obtained from the aponeurotic roof of the canal; viability of the artery was retained.

The three secondary or intermediate operations afforded successful, if not perfect, results. Of the three remote operations, one died.

The following are the records of these six cases.

Case 2.—Arterial hæmatoma of seven days' standing. A definite, stiff sac had formed around a lateral rent in the artery, almost amounting to a complete division. A double row of sutures, the second implicating the adventitia alone, was inserted, somewhat restricting the lumen of the vessel. The tibial pulse was diminished in volume, but was persistent. On the fourteenth day the peripheral blood pressure was determined as 90 mm. of mercury in the injured to 140 mm. in the sound limb. An uneventful recovery took place, but it has not been possible to trace the patient since he left France.

Case 3.—Arterial hæmatoma developing secondarily on the twelfth day in a patient with a fractured femur. Exploration revealed a through-and-through perforation of the artery. The two apertures were closed by suture, and an uneventful recovery took place. No observation of the peripheral blood pressure was made.

Case 4.—Secondary hæmorrhage occurring on the third day from a small shell wound. A rent a quarter of an inch long was sewn up, and the fragment of shell removed from Hunter's canal. The posterior tibial pulse persisted, but in reduced volume.

Case 5.—Aneurysmal varix of six months' standing. This man had been returned to duty after being wounded six months previously; the arterio-venous communication had not been discovered. The man was sent down the line because he complained of pain when marching. A vertical slit in the side of the superficial femoral artery was closed by suture, and the femoral vein was tied (Fig. 4, p. 174). Prior to the operation the peripheral blood pressure in the two limbs was equal to 140 mm. of mercury. After the operation it fell to 125 in the sound limb, and 110 in the affected one. The tibial pulse was retained, but was smaller in volume than that of the sound limb.

Case 6.—Arterial aneurysm of the common femoral artery of six weeks' standing. The bullet, which had entered above Poupart's ligament, passed downwards and wounded the common femoral artery on its posterior aspect. The sac dipped into the ilio-psoas muscle. The sac was separated from the artery, and the opening in the vessel closed. Early thrombosis took place at the site of the suture, and the posterior tibial pulse was obliterated; but the patient made a good recovery.

Case 7.—Arterio-venous aneurysm of superficial femoral artery at the apex of Scarpa's triangle. Vertical lateral slits in the artery and vein were closed by stitches. The wound, which communicated with an unhealed sinus in the buttock, was acutely reinfected by streptococcus, and the patient succumbed to toxæmia on the ninth day, after an attack of secondary hæmorrhage.

The series is too small to draw any wide conclusions, but it shows that in four of the operations the viability of the vessel was maintained, while in three it was certainly not. In no case was an ideal result attained, as estimated by the volume of the posterior tibial pulse and the peripheral blood pressure in the limb. The two fatalities were in no way dependent upon the nature of the operation performed, and the second could certainly have been avoided had not the presence of a deep sinus in the buttock been overlooked.

In Series II an attempt at temporary maintenance of the circulation by Tuffier's tubes was made in five cases, in two of which success was attained. In one of these, under the care of Colonel Kidd, C.A.M.C., the tube was left in position 21 days; the pulse persisted, and on the sixtieth day the peripheral blood pressure in the affected limb stood at 120 mm. of mercury as against 135 mm. in the sound one. In the second case, under the care of Captain J. Fraser, the tube was retained for 72 hours, and the patient was evacuated later with a persisting pulse. In two unsuccessful cases the limb in one became gangrenous and had to be amputated after 20 hours; in the second the tube was retained six days, when gas gangrene

supervened, and the patient succumbed after an amputation. The fifth case was one in which traumatic thrombosis having occurred the artery was incised, the clot evacuated, and a tube introduced. A fresh thrombus formed in three hours, and the artery was tied.

Conclusions.—The following conclusions may be deduced from the foregoing material.

(1) An operation for a gunshot injury of the femoral vessels in the region of the origin of the profunda calls for capacity and resource on the part of the surgeon. Any unnecessary loss of blood during the procedure gravely increases the possibility of gangrene of the limb and the risks to the patient's life.

(2) It is important to remember that a provisional ligature placed upon the common femoral artery has but little influence in restraining hæmorrhage from the branches of the profunda, and that ligature of both superficial and deep femoral trunks fails to control hæmorrhage from branches of the latter. When the field of operation allows, the application of an elastic tourniquet is preferable; if the injury be to the common femoral, the abdominal aorta may be controlled by an elastic tourniquet round the waist. Tubing about the calibre of the forefinger is the most suitable for the latter procedure.

(3) In no situation in the body is it more important to deal directly with the wounded spot. Putting on one side the risk of gangrene entailed by ligature of the main trunks, a proximal ligature sometimes fails to effect immediate control; it usually only checks secondary hæmorrhage temporarily, and in arterio-venous aneurysms it not only fails to cure but is also a procedure highly dangerous to the vitality of the limb.

(4) The results do not support the view that ligature of the common femoral artery is a more serious operation than that of the superficial femoral.

(5) Such results as are available favour the substitution of suture of the artery or vein for obliteration by ligature.

(6) The femoral artery is the vessel in which the provision of a temporary artificial conduit (Tuffier's tube) has furnished the most satisfactory results.

(7) Wounds of the femoral vein often produce a condition not readily discriminated from that resulting from wounds of the artery, the absence of an arterial bruit and local pulsation not being a certain sign. Such cases often present great operative difficulty, first in localizing the site of the wound, secondly in applying the ligature, because a wounded vein

is more difficult to isolate than a wounded artery in an œdematous and infiltrated limb.

(8) It is often impossible to determine whether the main trunks or their branches be the site of the injury, except by direct exploration and exposure.

Terminal results.—The immediate consequences of wounds and the obliteration of the femoral vessels by ligature are sufficiently set out in the preceding records; it is less easy to describe the terminal results.

In 77 of the cases included in Series I the notes afford information as to length of stay in hospital, and furnish some idea of the condition of the patients at the date of discharge. The average duration of residence in regular hospitals amounted to four months and nine days, with extremes of thirteen months and six weeks respectively. It may be added that the stay of the more successful cases ran from six weeks to three months.

The information as to the destination on discharge of the 77 patients was as follows :—

Returned to light duty.. .. .	8
Discharged on furlough	18
Discharged to convalescent hospitals.. .. .	7
Discharged to command dépôt	1
Transferred to auxiliary hospitals	4
Various disabilities reported, but not discharged the service.. .. .	9
No information as to condition	11
Amputations	9
Discharged as permanently unfit	10
	77

It may be assumed from this that a large proportion did not return to active service, a very unsatisfactory result in the case of a vessel which has been regarded as a favourable one for surgical treatment. It must, however, be borne in mind that many of the cases were complicated, and in a large proportion the wounds were infected.

Some information as to the condition of cases considered satisfactory at the time of discharge has been obtained from material collected at the hospitals of the Ministry of Pensions. A short abstract of eight consecutive cases, none of which is included in either series, and of which it is not possible to form any idea as to their proportional incidence, will best illustrate the conditions met with.

1. Foreign body removed from popliteal space and femoral artery tied in Hunter's canal, May 1918. In bed nine months. Ulcers on foot and heel,

latter cured by skin graft. After getting up, the limb has always swollen, ulceration of sole of foot commenced, and has persisted ever since.

December 1920. Swelling of foot and leg, circumference of calf, 12 to 15 ins. Ulcer over heel and head of second metatarsal bone in sole. Hyperæsthesia of sole, with anæsthetic patches around ulcers. The electrical reactions of the intrinsic muscles show R.D. Posterior tibial nerve probably involved in scar about heel.

2. Femoral artery tied 14th February, 1917. In bed four months with greatly swollen leg. The swelling has persisted, and ulcers develop periodically.

December 1920. Scar in centre of thigh. Great swelling of limb below; large area of pigmentation of leg. Pulsation palpable in dorsalis pedis artery. No sensory changes.

3. Arterio-venous lesion. Femoral artery and vein tied November 1915, in Scarpa's triangle. The leg and thigh have been swollen ever since, and the limb cold and heavy.

December 1920. Large scar in Scarpa's triangle. Limb tense and swollen. Two patches of pigmentation on front of leg. No pulsation palpable in arteries at ankle. No sensory changes.

4. Compound fracture of femur. Femoral artery tied December 1917. Eleven operations for necrosis of femur; was in bed two years and two months. Persistent eczema about wound in thigh, no pulsation, and no ulceration of leg.

December 1920. Deeply depressed scar in adductor region of thigh; eczema around scar. No swelling of leg or foot. Dorsalis pedis pulsating palpably. No sensory changes.

5. Arterio-venous lesion. Femoral artery and vein tied in June 1918. In bed four months. As soon as he got up the leg began to swell between the knee and ankle, and the veins became enlarged. An ulcer formed in February 1920.

December 1920. Scar at apex of Scarpa's triangle. Leg 1 in. larger in circumference than on sound side; foot little swollen. Veins enlarged and varicose, scattered patches of pigmentation, and the scar of a healed ulcer 3 in. by 3 in. No posterior tibial pulse. No sensory changes.

6. Fracture of pelvis and (?) right femur. Femoral artery tied at casualty clearing station, April 1915. In bed two and a half years; foot began to swell in 1916, and since he has been up the foot and leg have always been swollen. Ulceration of leg commenced in June 1920.

December 1920. Great swelling of foot and leg; numerous small superficial ulcers. No pulsation in arteries at ankle. A patch of diminished sensation on inner side of knee below patella, probably resulting from division of cutaneous nerves at the time of operation.

7. Femoral artery tied in Hunter's canal for secondary hæmorrhage, May 1915. Gangrene of the toes followed. The distal phalanges separated spontaneously and the stumps healed.

December 1920. Good useful limb; calf, $1\frac{1}{2}$ in. less in circumference than sound leg. Scars of old pressure sores on heel and in front of ankle. No œdema of leg, dorsalis pedis artery palpable, but not posterior tibial. Leg has never swollen.

8. Arterio-venous lesion, March 1918. Artery and vein tied and aneurysm excised from lower half of Hunter's canal, March 1920. Swelling of calf and ulceration of leg was present up to date of operation. The ulcer has healed, but the leg swells, and is painful when the patient walks.

December 1920. Wears an elastic stocking. Healed ulcer on outer side of leg; veins are enlarged above the scar. Superficial œdema of leg, no pulsation in posterior tibial artery at ankle, and palpable in dorsalis pedis.

The following points in these cases may be noted. No. 7 is the only good result, and this is a case in which gangrene is recorded. Otherwise, except for the loss

of mass in the limb and consequent diminution of strength, the conditions must be regarded as satisfactory. No. 8 may still improve. Nos. 4 and 6 are not fair examples, as in each case a fractured femur was present, and slow recovery was due to necrosis. In No. 6 the swelling was very great and extended over the whole thigh. The condition may be due to blocking of the pelvic veins in connection with the fractured pelvis.

Four types of limb as detailed below were illustrated by them. In all, the muscles were in a firm condition, resembling that seen in the early stage after ligature of the artery, which has been likened to "rigor mortis." The tension did not appear to be explained by the presence of sub-fascial œdema alone. In no patient was pulsation of the posterior tibial artery palpable at the ankle.

Type 1.—Large elastic calf, the appearance suggesting a large effusion between the layers of muscles. Firm but not œdematous. Varicose superficial veins. Tendency to ulceration, purple pigmented patches.

Type 2.—Giant limb, fairly elastic in consistence, but œdematous throughout. Patient complaining of weight of limb and asking to "have it off." Probably due to widespread thrombosis.

Type 3.—œdema reduced from rest in bed. Muscles hard and firm.

Type 4.—Definite inflammatory thickening in tissues of lower third of leg. Ulceration of sole of foot.

In one of the œdematous limbs, the skin of the leg was shining and eczematous, and the effusion of serum was so free as to leave a wet spot on the floor where the patient had been standing.

The Popliteal Artery.

Table X gives the particulars of wounds of the popliteal artery in the two series of cases.

The incidence of wounds on either side of the body is practically equal in both series. In Series I the same large proportion of wounds from bullets is met with as in the case of the femoral vessels, and no doubt from the same reasons. In one of every six cases the wounding missile was retained. One case of bayonet wound is included. The scanty records give little information as to the occurrence of primary hæmorrhage in Series I. In Series II it is stated to have been abundant in 16·4 per cent. of all cases.

TABLE X.

	Number.	Side of Body.			Missile.			Contusion or Spontaneous Thrombosis.	Primary Complications.			Secondary Hæmorrhage.	Gangrene.	Amputation.	Aneurysm.		Result.	
		Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.		Fracture.	Nerve Injury.	Wound of Knee Joint.				Arterial.	Arterio-venous.	Recovery.	Death.
Series I	59	27	30	2	22	22	15	1	8	3	5	14	11	23	18	8	50	9
Series II	85	24	26	35	10	20	55	7	2	5	14	9	39	25	11	17	80	5
Total	144	51	56	37	32	42	70	8	8	8	19	23	50	48	29	25	130	14

Secondary hæmorrhage necessitated operative intervention in 14 per cent. of the cases included in Series II. In Series I 14 cases of secondary hæmorrhage are included (23·7 per cent.), and no fewer than seven proved fatal.

Some form of hæmatoma or traumatic aneurysm formed in 54 of the total of 144 injuries. In Series I arterial aneurysms were the more common. In Series II arterio-venous lesions were in the considerable majority of 17 to 11, and as all the cases in this series were seen by the same observer, the numbers are probably the more accurate. There is no doubt that early obstruction of the vessels by pressure from clot forming in the strictly confined popliteal space rendered the early development of pulsating hæmatomata less frequent than in other regions, and at the same time necessitated earlier surgical intervention.

Complications.—Many of the patients were the subjects of multiple wounds, but the local wounds in either series were not often extensive. Large open wounds in this region accompanied by injury to the main vessels, and especially if complicated by division of the internal popliteal nerve, usually demanded primary amputation.

Concomitant wound of the knee joint was the most common complication, but neither series affords exact information on this point. In Series I it is said to have been present in five patients, and in two it was possibly the element which called for amputation. In Series II three cases in which the knee joint became infected were mentioned specially, but a number of instances of synovial effusion or hæmarthrosis was observed.

The following fractures complicated the vascular lesion in Series I: femur, four; patella, one; tibia, one. In two cases the ankle joint was wounded.

It is remarkable that in neither series are lesions of the popliteal nerves frequent. In Series I two instances of injury to the external popliteal and one of injury to the great sciatic nerve are recorded, and in Series II four injuries to the external popliteal, and one to the internal. A remark as to the serious effects following concomitant injury to the latter nerve and the main vessels appears above. This depends on the trophic effect, and perhaps, to a still larger degree, on the serious result of interruption of the anastomotic chain of vessels which accompanies the nerve. Further, the comparative mobility of the internal popliteal favours its escape by displacement.

Contusion.—In Series I only a single case of contusion of the popliteal artery is included, but it is characteristic. The patient had a secondary hæmorrhage from a shell wound of the popliteal space on the eighth day. Exploration revealed a wound of the popliteal vein and a contused artery, the artery was ligatured and the vein treated by forcipressure.

In Series II seven cases are included. Thrombosis of the artery was the prominent feature, and in six gangrene of the limb necessitating amputation was the direct consequence. In two the vein was wounded and in one of them it was ligatured primarily; in each the tibial pulses were extinguished at an early moment and gangrene was established on the sixth day. In two cases arterial hæmatomata developed secondarily on the thirteenth and eighteenth days respectively, and in both amputation became necessary, in one for gangrene, in the other for toxæmia, dependent on a large infected wound; in a fifth case a fractured femur was present, gangrene occurring on the fifth day; in the sixth, gangrene commenced on the second day; in the seventh, secondary hæmorrhage occurred on the third day. In the three last, amputation was performed, and one patient died of toxæmia.

Gangrene.—The incidence of gangrene in these injuries was enormously high. This appears to be in part dependent upon a somewhat scanty collateral circulation, as evidenced by the frequency of gangrene following traumatic local thrombosis, and partly on the pressure which is exerted on the vessels when the popliteal space becomes distended by extravasated blood. The gangrene is usually extensive, involving the greater part of the leg; thus in Series II, among

21 cases of gangrene occurring independently of operation, in only two was it limited to the foot. Among 18 post-operative cases it was limited in two to the toes, in three to localized areas on the feet, in three the whole foot was involved, and in 10 the gangrene extended to the leg. Gangrene followed injuries to the lower two-thirds of the vessel more frequently than in the case of injuries to the upper third.

In view of the current opinion that local pressure is an important element in the causation of gangrene, it has been suggested that imminent or commencing gangrene should be promptly treated by ligature of the vessel, thus affording relief to the distended popliteal space. Eight such operations are recorded by Makins, but the results do not afford much support to the local pressure theory. In five instances no relief was obtained, but in two a successful issue followed.

No analysis has been made of the 11 cases of gangrene recorded in Series I because the information is obviously not in accord with the number of amputations performed (11 and 23), and also because there is practically no reference to the limit of the gangrene.

Among the 14 cases of secondary hæmorrhage included in Series I, two were treated by primary amputation, and of these one died. In three cases a proximal ligature was applied to the femoral artery. Of these patients two died, probably as a result of general septic infection from the original wound, and in the third gangrene of the limb supervened, rendering amputation necessary. In seven cases the wound in the vessels was treated by local ligature, presumably applied above and below the wounded spot. Of these patients four were subjected to secondary amputation and died, two from septic infection, one shortly after amputation of the limb, and one from pulmonary embolism. In two cases anæmic gangrene followed, and in two gangrene from anaërobic infection.

The following table includes the whole of the operations performed for injury to the popliteal vessels in Series I. Two of the 59 cases shown in Table X were not operated upon; one was a case of a contused artery and wounded vein. In one instance an arterial aneurysm is stated to have been cured by flexion of the limb—a dangerous precedent if one may judge from the results following treatment of spontaneous aneurysm by this method.

Treatment by Ligature.—Proximal ligature of the femoral artery was resorted to on nine occasions. In one instance ligature was at the seat of election to control hæmorrhage

TABLE XI.

Nature of Operation.	Numbers.	Indications.				Accidents.		Results.	
		Secondary Hæmorrhage.	Arterial Aneurysm.	Arterio- venous Aneurysm.	Aneurysmal Varix.	Gangrene.	Amputation.	Recovery.	Death.
Proximal ligature—									
External iliac	1*	—	1	—	—	—	—	—	1
Femoral	9	3	2	1	—	1	2	7	2
Direct ligature above and below	36	6	9	6	—	5	13	31	5
Excision	2	—	1	—	1	—	—	2	—
Suture	3	—	1	—	—	—	1	3	—
Plugging	1	—	—	—	—	—	—	1	—
Primary amputation ..	4	—	—	—	—	—	—	3	1
Totals	56	9	14	7	1	6	16	47	9

* Operation chosen on account of great swelling of thigh.

from the popliteal space after evacuation of septic clot. Recurrent secondary hæmorrhage followed, with death from septic infection and exhaustion. In a second case ligature of the femoral artery had to be followed by an amputation, the patient eventually succumbing to general infection on the forty-third day.

In three cases of ligature for wounds recovery followed, but the limb was not left in good condition in two instances.

In one case resort was had to ligature at the seat of election, in which secondary hæmorrhage occurred after local ligature of the popliteal. Gangrene followed and necessitated amputation of the thigh. Recovery ensued.

In one case of arterio-venous aneurysm the operation succeeded, but in two cases of arterial aneurysm it failed.

Direct ligature, presumably above and below the wounded spot, was resorted to 36 times. It will be observed that gangrene followed in five cases (13·6 per cent.), and amputation became necessary in 13 (36·1 per cent.). In two cases anaërobic infection led to gas gangrene; one patient died and one recovered after amputation.

These results probably give by no means a reliable indication of either the frequency of occurrence or of the fatality of

anaërobic infections in connection with lesions of this artery. Nor is the incidence of anæmic gangrene accurate; it is probable that gangrene was the indication for the great majority of the amputations, but the notes are not explicit on this point.

Of nine cases of arterial aneurysm, the majority of which were in the hæmatoma stage, cure resulted in eight. This was a fairly good result, as five were discharged to light duty or furlough at periods of from three to eight months. In two others the result was poor. One patient suffered amputation subsequently as a result of suppuration of the wounded knee joint, and one patient died from pulmonary embolism.

In six cases of arterio-venous aneurysm the results were far less satisfactory. One aneurysmal varix was cured, and two patients were sent on furlough about six months after operation; in one of these the artery had been tied and the vein sutured. In two cases gangrene necessitated amputation, and one of these died the day after the secondary operation. In the sixth case the artery was tied above and the vein below the communication, and failure resulted, the "thrill" persisting.

Removal of the sac and ligature of the artery and vein above and below were performed twice with success.

In Series II local ligature of the popliteal vessels was performed 48 times, with the following results.

TABLE XII.

Indication for Ligature.	No. of Cases.	Gangrene.	Amputation.	Recovered.	Died.
Primary hæmorrhage.. ..	19	8	5	19	—
Secondary hæmorrhage	8	3	3	7	1
Pre-operative gangrene	5	5	3	5	—
Hæmatoma, arterial	6	1	—	6	—
Hæmatoma, arterio-venous ..	5	—	—	4	1
Removal of missile	4	1	1	4	—
Wound of popliteal vein	1	1	—	1	—
Totals	48	19	12	46	2

In 24 cases the artery alone was ligatured; of these, 11 suffered from arterial gangrene (45·8 per cent.) and two from gas gangrene.

In 24 the artery and vein were ligatured simultaneously; of these arterial gangrene occurred in six (25 per cent.); but as in two of the latter incipient gangrene was the indication for operation, the percentage may be considered as 16·6.

It will be observed that of the 11 cases of aneurysm, one operation for arterial hæmatoma was followed by gangrene, and one for arterio-venous aneurysm by death. All were early cases, and in all the nine recoveries the local condition was cured.

Suture.—Suture of the artery was performed thrice in Series I. In a small arterial aneurysm the sac was excised and the opening in the arterial wall closed. In a second case one wound was sutured, but as hæmorrhage continued from a perforation in the opposite side of the wall, the surgeon ligatured the vessel. In a third case the artery was sutured and the vein tied, but secondary hæmorrhage occurred; the limb was amputated twelve days later, and the patient recovered.

In Series II suture of the wounded artery is recorded in the following six cases.

Case 8.—Operation on sixth day. A long, ragged wound, closed by vertical suture; on the next day the anterior tibial pulse was good. The wound of the soft parts was an extensive one; it suppurated, and the patient eventually died. Thrombosis of the artery is probable, as secondary hæmorrhage did not occur. No other details are available.

Case 9.—Operation on seventh day. A ragged hole in the artery was sutured vertically. The pulses returned, and on the thirty-fifth day the blood pressure in the leg was equal to that on the sound side.

Case 10.—Operation on the third day for recurrent hæmorrhage. A lateral wound in the artery was sutured, and the tibial pulses returned. On the eighteenth day the pulses were still retained. The blood pressure in the injured leg was 99; in the sound one, 119. A secondary hæmorrhage occurred on the twenty-third day; the wound was reopened, and the vessel found to be thrombosed. A double ligature was applied, and the patient made a good recovery.

Case 11.—Operation for primary hæmorrhage. Wounds on the anterior surface of both artery and vein sutured. Three weeks later the patient arrived in London with a practically normal foot and good tibial pulses. Ten days later the pulses had disappeared, but the foot and leg remained in good condition, with slight œdema (1 in. increase of circumference of calf).

Case 12.—Operation on seventh day. Arterio-venous anastomosis established; transverse wound of posterior surface of artery immediately above bifurcation sutured transversely. Pulses present at end of operation and persisted. Ten days after the operation the blood pressure in the two legs was equal (110 mm.).

Case 13.—Arterial hæmatoma. On the twelfth day the swelling increased, and the popliteal space was explored. A lateral opening in the artery was closed by suture, and the sac plicated. At the end of a month the patient came to England, and two months later he was still in hospital with weakness of the muscles of the leg.

This small series is suggestive, as in no instance did gangrene occur, and in the death which took place the wound of the soft parts was responsible. In cases 9 and 12 the result was apparently ideal; In cases 10 and 13 it was good; and the same must be said regarding case 11, although there is no doubt the vessel eventually suffered thrombosis.

Use of Tuffier's Tube.—In six of the cases included in Series II a Tuffier's tube was employed. In four of these no gangrene occurred; in one the result is uncertain. In all clotting occurred rapidly. This may be partly due to the fact that introduction of the tube into the distal end of the vessel is often difficult, and needs a good deal of manipulation. The method is always worthy of trial if suture is impracticable, especially in recent injuries. The following are notes of four of the cases.

Case 14.—Arterio-venous hæmatoma explored, ninth day. Tuffier's tube introduced in artery and vein tied. Wound eventually suppurated. Ultimate result, discharged permanently unfit. No record of tibial pulse; but foot was painful at times.

Case 15.—Retained shell fragment. Arterial hæmatoma, extension on ninth day. Longitudinal tear of artery and of vein, but the latter was thrombosed. Small tube introduced and removed on the fourth day; it was obstructed in less than twenty-four hours. The leg and foot did well. Five months later the man was reported to be getting about on furlough, but with some restriction of movements of the knee, and with a numb foot "at times."

Case 16.—Single wound, followed by severe primary hæmorrhage. Tube was tied in on the third day; the absent tibial pulses did not return. The condition of the foot improved, but the ultimate result is not known.

Case 17.—Arterial hæmatoma. Operation on the eighteenth day. The artery was almost completely divided. A tube was tied in and retained three days, pulsation returning in the tibial pulses. The patient made a good recovery.

In two cases reported from casualty clearing stations, pulsation in the tibials lasted in one for 45 minutes only, and in the second the tube was left for five days. In neither of the cases did gangrene supervene.

Amputation.—In Series I amputation was performed 23 times, two of the operations being primary. The notes suggest that the indications were:—wound, three; septic infection, eight; and gangrene, 11. It is more than probable that gangrene was present to some extent in most of the cases in which septic infection is given as the indication. Six, or 26 per cent., of the patients died.

In Series II 25 amputations are recorded, all of the thigh except one. Three, or 12 per cent., of the patients died. Gangrene was the indication in the great majority.

General prognosis.—The general results as to recovery show that gangrene of the limb followed the injury or the operation in 34·7 per cent. of all cases, in 33·3 per cent. amputation became necessary, and 9·72 per cent. of the patients died.

These results are to be considered the immediate consequences of the injury. Such evidence as exists as to the ultimate condition of the patients is no more satisfactory.

Of 30 of the cases included in Series I the average length of stay in hospital amounted to four months and two weeks, with extremes of two months and eight and a half months. The results are recorded in 25 of these. Three of the men were reported as returned to light duty, two were discharged to depot, four went on furlough and might have rejoined, two were reported as good results, seven were said to have been suffering such disabilities as "weakness, stiff knee," and seven were discharged as permanently unfit with the loss of the limb.

An attempt was made to follow up the history of the cases recorded in Series II. Of sixteen patients, of whose condition some details were obtained, two rejoined their unit, three were sent on furlough, four were still suffering from disabilities, and seven had been discharged from the service as permanently unfit. No cases of amputation are included in the last figure.

All available information is to the effect that the prognosis, both immediate and remote, is very unsatisfactory in these injuries. The local damage tends to be severe in type as a result of the anatomical conditions, and the increased risk due to the obliteration of a main trunk near its terminal division is exemplified in the common inability of the collateral circulation to prevent the occurrence of gangrene or to furnish a sufficient blood supply for the future nourishment of the limb. It is a striking fact that local obliteration from thrombosis is as dangerous as that due to ligation by the surgeon.

Certain propositions may be laid down for guidance in the treatment of these injuries.

(1) In view of the frequency of gangrene of the limb, it is of great importance to bear in mind the danger of applying a provisional tourniquet and leaving it for any material period in position. In no position in the whole body can a tourniquet so easily and effectively control the circulation and stop hæmorrhage, but, equally, in no position is the tourniquet likely to act with such disastrous effects. Numerous instances of this fact were observed after this treatment applied by the wounded man himself, his comrades, orderlies or even the surgeon.

(2) Experience has shown that operations on the popliteal artery, in what may be called the intermediate stage, are followed by many unsatisfactory results. For this reason operation should, if possible, be avoided. Leaking or extending arterial hæmatoma, or the occurrence of secondary hæmorrhage,

forms the most justifiable indication. Arterio-venous hæmatomata rarely demand intervention during this period.

(3) The question arises whether it is not better to deal with injuries to the popliteal artery primarily, if existing conditions are satisfactory. An attempt to settle this question was made in the casualty clearing stations, but the unfortunate loss of many of the records in March 1918 has resulted in but meagre material being available.

In 28 instances, primary ligature was undertaken for persisting hæmorrhage. Of these 16 are obtained from Series II, and 12 from direct reports furnished by casualty clearing stations. In 20 cases, both artery and vein were occluded, with six cases of gangrene; in eight, the artery alone was ligatured, with two cases of gangrene. Consideration of the combined series shows that of 28 cases gangrene is known to have occurred in eight (28·5 per cent.), and seven patients (25 per cent.) were subjected to amputation. It must be added that, as regards the 12 cases in which reports from casualty clearing stations have been utilized, two patients were so ill as to need blood transfusion, and in only two does the history after operation extend beyond a few days to a week; hence the numbers may be more favourable than was actually the case. None the less, the apparent reduction of the general incidence of gangrene from 45·8 to 28·5 per cent. affords food for reflection.

(4) When primary hæmorrhage has been severe and the patient is highly anæmic, the insertion of a Tuffier's tube may be tried.

(5) The ligature when employed should always be local. Results have shown proximal ligature of the femoral artery to be ineffective and dangerous. Moreover, provisional control of the arterial circulation is particularly easy in this operation.

(6) Operations for aneurysmal varix in this position, which entail ligature of the vessel, should not be done.

(7) Of all the arteries of the extremities, the popliteal is that in which it is most desirable to suture the wound of the vessel, and maintain the circulation in its normal path.

(8) Gunshot wounds of the popliteal vein are particularly serious, because they are so liable to be associated with a contused or partially injured popliteal artery.

(9) Delay in the development of hæmatomata, or traumatic aneurysms, is common in this situation and varices are often overlooked. Both aneurysms and varices have often escaped notice when the knee joint is wounded and the surgeon's whole attention has been devoted to the damaged articulation.

The Arteries of the Leg.

Table XIII is compiled from 112 cases in Series I, and from the small number of 26 which occurred in Series II.

TABLE XIII.

Artery.	Side of Body.				Missile.			Contusion or Spontaneous Thrombosis.	Primary Complications.				Aneurysm.	Result.			
	Number.	Right.	Left.	Not Recorded.	Bullet.	Shell.	Not Recorded.		Fracture.	Nerve Injury.	Wounds of joints.	Secondary Hemorrhage.		Gangrene.	Amputation.	Arterial and Arterio-venous.	Recovery.
Anterior tibial	26	11	10	5	8	5	12	—	7	—	—	13	1	—	5	25	1
Posterior tibial	97	38	50	9	25	24	48	—	29	—	—	53	9	—	30	66	11
Peroneal ..	4	2	1	1	1	—	3	—	2	—	—	2	2	—	1	4	—
Both tibials ..	7	2	3	2	2	3	2	—	—	—	—	4	—	—	—	5	2
Ant. tibial and peroneal ..	3	1	1	1	—	—	3	—	—	—	—	2	—	—	—	3	—
Post. tibial and peroneal ..	1	1	—	—	—	—	1	—	—	—	—	1	—	—	—	1	—
Totals ..	138	55	65	18	36	33	69	—	38	—	9	75	12	—	37	124	14

The small number in Series II is explained by the fact that the majority of these injuries were treated promptly, and were not considered of a serious nature, until the occurrence of secondary hæmorrhage. Comparatively few cases settle down to be treated later as traumatic aneurysms, and beyond this neither series includes the large number of instances in which the vessels were tied for hæmorrhage in the primary wounds. This last fact is one of first importance in considering the danger attendant on wounds of the leg involving the main vessels. Surgeons working in the front line unanimously regarded the complication as grave, and probably the development of anaërobic infection, after ligature of these vessels, was more common and more destructive than in any other region of the body.

The number of bullet wounds is shown to have been large, as is the case in most localized arterial injuries.

Complications.—The most important were 38 fractures of the leg (27·5 per cent.) ; wounds of the knee joint, six ; of the ankle joint, three ; and in several cases the tibial nerves were

involved. The notes do not allow any exact computation of the last complication to be made, but it was responsible in several cases for a poor ultimate result.

Secondary Hæmorrhage.—This was very frequent, and as a rule occurred at an early date ; it was met with in 54 per cent. of all the cases, and was the chief factor in the mortality.

Gangrene.—This occurred in 8·6 per cent. ; in more than half the instances amongst the 22 cases in which a proximal ligature was applied in the ham or thigh. It occurred twice amongst seven cases in which both the tibials were ligatured, but not once amongst the four cases in which a wound of the peroneal was associated with one of the tibial.

Aneurysms.—Some form of aneurysm was met with in 27 instances in Series I (26·8 per cent.), and in 10 of 26 cases in Series II. The notes are not explicit as to the variety, but it is evident that the great majority were dealt with in the hæmatoma stage during the first fortnight, that a common indication was secondary hæmorrhage, and hence it may be inferred that infection was a prominent factor in the necessity of surgical intervention. The notes suggest a large majority of purely arterial hæmatomata. This is not the case with aneurysms met with at a later date, when the arterio-venous variety is the more frequent.

The great preponderance of wounds of the posterior tibial artery is noteworthy ; about the same proportion was met with in both series, and also in the set of primary operations recorded below. It is therefore probably the rule, and is no doubt explained by the more protected position occupied by the anterior tibial vessels.

Methods of Treatment.—In a few instances plugging of the wound was tried ; most of these came to amputation.

In five instances amputation was a primary measure for the treatment of secondary hæmorrhage in an infected limb. In ten the procedure was secondary to ligature of the vessels. Four patients died.

Table XIV shows the result of ligature.

The immediate result must be regarded as good, since a large proportion of the operations was performed on infected limbs. The proportion of gangrene is, however, high, especially as this table contains few, if any, instances of serious anaërobic infection. The same remark applies to the number of amputations. The most important feature is the manifestly worse result obtained when proximal ligature was adopted. It will be observed that gangrene occurred in 7 per cent. of the cases

of ligature, that 8·7 per cent. of the operations were followed by amputation, and that the mortality was 6 per cent.

TABLE XIV.

Vessel Implicated.	No.	Gangrene.	Amputation.	Recovered.	Died.
<i>Local Ligature—</i>					
Anterior tibial	17	—	—	17	—
Posterior tibial	72	4	7	69	3
Peroneal	3	—	—	3	—
<i>Proximal Ligature—</i>					
Popliteal	8	2	1	7	1
Femoral	14	2	2	11	3
Totals	114	8	10	107	7

The following observations may be made:—

(1) Injuries to the tibial arteries call for prompt attention. In the absence of this, even an insignificant leak soon leads to distension of the space between the superficial and deep layers of muscles; this extravasation of blood leads to technical difficulties in operation, and opens up extensive possibilities of infection.

(2) The fact that blood extravasations are retained and that consequent local pressure checks early hæmorrhage from the external wound accounts for the number of cases in which treatment is likely to be expectant; while the frequency with which secondary hæmorrhage occurred in the series of cases under observation abundantly demonstrates the danger of delay.

(3) In infected wounds, a partially damaged or contused vessel is a greater source of danger than a considerable perforating injury, from the fact that delay is encouraged. Hence the peripheral pulse should always be carefully examined.

(4) Plugging of the calf is a dangerous procedure, on account of the ease with which extravasation may continue unnoticed in this region.

(5) Difficulty frequently exists in determining which of the main vessels of the leg is implicated, or the surgeon may be satisfied by detection of a wound of one of them. To avoid accidents in this direction, auscultation should always be employed. It may be added that pulsation is often absent in a distended calf, yet the presence of the characteristic systolic bruit will always show that an open vessel exists.

(6) In dealing with hæmorrhage from the calf, a central

incision is preferable to the classical incision for the posterior tibial artery. It allows an extensive exploration to be made, either of the posterior tibial, the peroneal or the origin of the anterior tibial, and also a thorough evacuation of any clot present. The results shown by the table emphasize the fact that proximal ligation is a measure to be always avoided if possible.

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CHAPTER IX.

GUNSHOT WOUNDS OF THE JOINTS.

INJURIES to joints occurred in about 4 per cent. of all wounds sustained during the war. Their importance, as regards danger to life and limb, was quickly recognized and in the earlier part of the campaign the treatment of wounded joints advanced more rapidly than that of wounds in other parts of the body.

Four phases may be distinguished in the development of the methods used in treating wounds of joints.

Phase I.—In the early stages of the war attention was concentrated on drainage, to the exclusion of all other methods of treatment. With the exception of some simple perforating wounds of joints, practically every case suppurated, and treatment by incision and the insertion of large tubes was adopted. In addition, it was customary to irrigate the joint freely at each dressing, often with considerable force, with the result that any protective adhesions that had formed were broken down and constant spread of the sepsis occurred. To ensure drainage heroic measures aiming at free opening of the joint cavity were adopted; a good example of this type of treatment was the method advocated for drainage of the knee-joint in which the ligamentum patellæ and crucial ligaments were divided and the knee was put in extreme flexion.

The results of these methods were lamentable: the death-rate for the larger joints was very high, the amputation-rate was enormous, 60 per cent. for knee-joint cases uncomplicated by injury to bone, and at least 80 per cent. where there was an associated fracture; and the functional results in those limbs that were saved were almost invariably bad as regards movement.

Phase II.—Early in 1915 Colonel H. M. W. Gray, writing in the *British Medical Journal*, described the methods he had introduced at a base hospital, and advocated their wider adoption. The methods he recommended were briefly as follows: (1) adequate immobilization of the joint on a suitable splint, with extension if possible, a point which had hitherto been neglected to a large extent; (2) excision of the infected soft parts; (3) lavage of the joint cavity after removal of the projectile if retained; and (4) closure of the capsule of the joint.

He pointed out the inefficiency and harmfulness of drainage tubes inserted into the joint cavity, and in infected cases showed that better results were to be obtained by arthrotomy with drainage down to, but not into, the cavity of the joint, than by inserting tubes into the joint itself.

An enormous improvement resulted from the adoption of these methods although most of the treatment had necessarily to be carried out at the base, as at this time operating in casualty clearing stations was neither so frequent nor so effective as it was at a later date, and the necessity of early excision of infected tissues had not been fully realized.

Phase III.—In the summer of 1916 the Carrel-Dakin method of treating wounds was first adopted in the British armies. This method, applied to the superficial wound, together with the adoption of the Thomas' splint for the early immobilization of knee-joints, resulted in a marked decrease in suppuration, and gave still better results in all joint cases. Further, where suppuration occurred in a joint, the use of Carrel tubes for overcoming the infection was the means of saving many limbs and lives. With the adoption of the Carrel-Dakin methods, the importance of the early excision of infected tissues as an essential feature in wound treatment began to be realized.

Phase IV.—In the spring of 1917 the early and free excision of the injured area had become the standard method of treatment for the majority of wounds, and already much work had been done with a view to effecting primary or delayed primary suture in as many cases as possible. By the middle of 1917 the technique had so far advanced that healing by first intention was obtained in at least 70 per cent. of all wounds so treated. The application of these methods to gunshot wounds of the joints marked a further improvement in results. In one group of casualty clearing stations in which 79 joint cases of all classes were treated by these methods, healing by first intention resulted in 69 and suppuration in 10 cases only. In the same way at the bases the amputation-rate fell from 25 per cent. in 1916 to 7 per cent. in 1917, and the death-rate from 15 per cent. to 8 per cent.

With the improved methods of wound treatment and earlier and more satisfactory healing, attention was turned to the improving of the ultimate functional results. Early mobilization of the injured joints as soon as the wound was healed was advocated and carried out; improved splints, jointed to allow of movements, were designed, and special devices, such

as that of Major Everidge, were planned for early mobilization of the knee-joint. As a result of these methods the ultimate disability from a wound of the joint was greatly diminished, and apart from cases associated with severe bony injury or marked sepsis, very little restriction of movement resulted.

The general policy in the British army was to treat aseptic cases by early mobilization, while in the case of infected joints great stress was laid on the necessity of adequate fixation of the joints. It is of interest to note in this connection that M. Willems, in the Belgian army, treated numbers of suppurating joints by arthrotomy and early movement, the patient being encouraged to move the limb as much as possible. Good results were obtained by these means in M. Willems' hands, but the method was never practised on a large scale in British hospitals.

General Principles of Treatment.

Most joints are lined with synovial membrane of a varying degree of complexity in arrangement, in very few cases presenting a simple sac. This complexity of arrangement acts in two ways: first, it tends to limit sepsis to one compartment of a joint in the early stages of infection; and secondly makes sterilization difficult, if not impossible, in the later stages when the infection is diffused throughout the joint cavity. Synovial membranes have a greater capacity for overcoming infection than is often imagined and further have a good power of repair. This repair is effected by the formation of plastic adhesions which, while preserving the limb, tend to cripple joint movements. These adhesions are formed very rapidly, and several cases of fine fibrinous adhesions in joints occurring within twelve hours of the injury have been observed. The power of resistance possessed by the synovial membrane probably depends in part on the epithelium lining it, and in part on the character of the synovial fluid. Destruction of the epithelium and gross changes in the synovial exudate are marked by exacerbation of symptoms and often by septicæmia. For these reasons any powerful antiseptic likely to injure the epithelium, or to inhibit the formation of the synovial exudate, is to be avoided in the treatment of injuries to joints.

The articular cartilages are nourished partly through the bone over which they lie and partly through the synovial fluid bathing them. Changes in the synovial fluid may greatly impair the nutrition of the cartilage, which becomes thicker and

softer ; separation of or injury to the ends of the bones forming the joint may more or less completely cut off the blood supply to the fragment and, in consequence of the impairment of nutrition, necrosis of bone and softening of cartilage often result. Erosion of the softened cartilage is a secondary phenomenon, due in most cases to pressure ; it can be avoided or diminished by adequate extension. The importance of "bruising" of the cancellous tissue at the ends of the bones forming the joint must not be overlooked ; "bruised" tissue is especially prone to be attacked by sepsis, and in the case of bone a spreading osteomyelitis may occur.

These factors have an important bearing on the treatment and ultimate prognosis in cases of injuries to the joints.

In the forward area treatment should be confined to sterilization of the skin and the application of an adequate dressing firmly applied. All wounded joints should be immobilized by bandaging to the trunk or by splinting, and in the case of the knee-joint extension and immobilization must be obtained by the use of a Thomas' splint. As soon as the joint has been adequately immobilized no further interference should be undertaken until the patient reaches the casualty clearing station. The early injection of antiseptic fluids into wounded joints has been advocated, but it is more likely to do harm than good in the majority of cases.

In the casualty clearing station under ordinary circumstances all cases of joint wounds, with the exception of one type, should be regarded as urgent and as requiring early operation. The one exception is the case of a perforating bullet wound in which the entrance and exit wounds are "leech-bite" in type, without concomitant grave injury to bone or vascular injury. Such cases, after careful sterilization of the skin and firm bandaging over a bulky dressing, travel satisfactorily, provided the joint is adequately immobilized, and rarely require any subsequent interference.

During times of stress it may be necessary to select cases likely to stand evacuation without grave risk. This selection is a matter of great difficulty, and should be based on the size and position of the wounds, the size and nature of the projectile, the presence or absence of severe effusion, and associated injuries to bones or vessels. Wounds caused by shell fragments and grenades are definitely more dangerous than clean rifle or shrapnel bullet wounds, and increase in severity with the size of the fragment. Open wounds with free escape of synovia, especially if situated in the posterior

aspect of the joint, are relatively less dangerous than valvular wounds. Great distension of the joint, comminution of bone, and vascular injuries are all urgent indications for interference.

An X-ray examination should be made in every case of joint wound, irrespective of whether the missile is retained or not, as an unsuspected foreign body or a bone injury discovered beforehand may modify the operative procedure. In the localization of retained projectiles more importance is attached to stereoscopic pictures, preferably taken in two planes, than to other methods.

Prior to the operation the joint should be moved as little as possible and, in the case of most joints, splints should be retained until the patient is under the anæsthetic. At operation the most careful aseptic technique is essential; a wide area of skin must be prepared, and two sets of instruments are necessary, one for the preliminary excision of the infected tissues, and the second for the toilet and closure of the joint. A tourniquet is of value in wounds involving the joint alone, as its use gives an unobscured view and prevents blood flowing over infected tissues into the joint cavity. Tourniquets, however, may cause harm where there are associated muscle injuries and especially if there is incipient gas gangrene.

The wounds themselves are treated by excision, *en masse* if possible, down to and including synovial membrane. This excision must be performed cleanly and freely with a sharp scalpel, and never with scissors, which tend to cause bruising. The ideal instrument to use is the American "safety razor blade" scalpel.

The foreign body can often be removed at this stage through the wound incision; if, however, it is not easily obtainable, gloves, towels and instruments are changed and a second incision is made, planned so as to give free access to the missile. The joint is then freely irrigated with large quantities of a non-irritating fluid such as saline, flavine (1 in 2,000) or eusol and saline in equal parts. Irrigation should be associated with movements of the joint, so as to ensure that the fluid reaches all parts of it; free irrigation will often dislodge a retained and unlocalized foreign body, and is especially valuable for the removal of fragments of clothing and other material. Minute foreign bodies which are not readily found may be left; metal fragments embedded in bone should be removed only if easily accessible, the bone cavity being curetted afterwards and lightly smeared with B.I.P. or flavine paste. In all cases where it can be done, the resulting bone cavity should be

excluded from the joint by a flap of synovial membrane. Other bone injuries are treated on the same lines, namely, by gouging, application of paste and, if possible, exclusion from the joint cavity.

After completing the cleansing of the joint cavity a clean set of instruments and towels is taken, and the synovial membrane and capsule of the joint are carefully sutured with catgut so as to close the joint cavity completely. In extensive wounds this may be difficult, but by mobilization of the synovial membrane and by the use of fascial or other grafts, very large defects can be covered in if the operation is carefully carried out. If complete closure is impossible the wound should be packed with gauze soaked in sterile liquid paraffin, which prevents oozing and promotes closure of the joint by adhesions; over this pack a bulky dressing is applied, fixed by very firm bandaging. Where the joint can be effectively cleansed and closed it is usually advisable to suture skin and soft tissues also, leaving a rubber tissue "cigarette" drain or small tube in at one corner. In wounds treated late, secondary suture of the soft parts is safer, in which case the wound is lightly packed with gauze either dry or soaked in 1 in 2,000 solution of flavine. Adequate immobilization, if possible with extension, is then provided by means of suitable splints.

Cases of injuries to the joints should be retained in casualty clearing stations for four or five days, or longer if possible, but in times of stress they may if suitably splinted be evacuated immediately after operation.

These principles apply to cases treated within twenty-four hours of wounding. In cases coming under treatment later on, where diffuse septic infection is well established and infected fluid is escaping from the joint, the Carrel-Dakin method after excision of the wound often gives satisfactory results as regards preserving the limb. Additional openings into the joint for the introduction of the tubes are usually necessary, and care must be taken to ensure that every recess of the joint is reached by the irrigating fluid. The Carrel tubes should be changed on the second day and removed on about the fourth day, provided that the general condition is satisfactory; secondary suture may be performed two or three days later and should be carried out, if possible, without removing the limb from the splint, as any excessive movement is liable to light up infection. The further management of late and infected cases is considered in more detail later.

Conservative treatment on the lines indicated above should be

carried out whenever possible ; broadly speaking, age, debility and multiplicity of wounds are contraindications as in such cases too great a risk to life may be run in attempting to save a severely damaged limb.

Extreme comminution of bone, associated injury to main vessels and hopeless destruction of nerves are also indications for primary amputation.

Primary excisions on formal lines are very rarely required and are generally unsatisfactory ; removal of bone should be confined to those portions which are hopelessly damaged or severely soiled.

At the base the cases may be divided into two classes : (1) those that have, for some reason, been evacuated without operation, and (2) those that have been operated upon in the forward area.

In the first class, those with through-and-through bullet wounds with tiny entrance and exit may still be treated on expectant lines, any excessive tension in the joint being treated by simple aspiration, the fluid withdrawn being examined for organisms. More severe injuries, due to shell fragments, are treated on lines similar to those adopted in casualty clearing stations. In such cases any excessive movement or manipulation is to be avoided, as sepsis is usually established and movement may cause extension to parts of the joint not yet affected. The wound is excised *en masse*, and foreign bodies are removed ; the joint cavity is then very freely irrigated with eusol and saline, or with 1 in 2,000 flavine solution in cases in which no very marked sepsis is present, as, for example, where the joint fluid is only slightly turbid with but few flakes in it and the temperature and pulse-rate are not markedly raised. The joint cavity is then closed with catgut sutures ; the soft parts and skin are left open and either lightly packed with gauze or treated by the Carrel-Dakin method.

Where sepsis has been definitely established and is severe a different line of treatment is necessary. In these cases the general condition of the patient is bad, the tongue is furred and dry, the pulse is rapid, the temperature is high, and there is much pain. Here, in the first instance, after excision of the wound, the joint cavity is carefully explored and any foreign body removed ; in so doing every care must be taken to avoid breaking down any protective adhesions. The Carrel-Dakin method of treatment is then applied to the obviously infected area of the joint, if there is any localization, or in all areas if there is none, and the ~~limb~~ is adequately

immobilized with extension. Localization of the infection is indicated by a rapid amelioration of the general symptoms ; if, however, general infection has occurred and is not overcome by this line of treatment more radical measures are necessary.

In the class of case in which operation has been performed before the patient reaches the base, the following general principles of treatment should be adopted :—

- (a) Very careful readjustment of the splint and extension should be carried out ; very often pain, pyrexia, and exudation abate with complete rest and immobilization of the joint.
- (b) Careful attention must be paid to the general condition of the patient as shown by tongue, pulse, temperature, appetite and sleep. Insomnia, loss of appetite and a rapid pulse are all bad signs although the local condition may appear to be good.
- (c) The condition of the joint calls for careful investigation. The following signs are of importance as indicating dangerous infection : sloughy condition of the external wound, especially if it is abnormally dry, effusion into the joint with pain, and œdema of the limb below the injured joint.

If no untoward symptoms are present on the arrival of the patient, or if the case settles down satisfactorily on readjustment of the splint, secondary suture is performed, if required, on the fourth to the sixth day. As soon as the wounds are healed, generally about the eighth day in the case of primary suture and the fifteenth day in case of secondary suture, movements of the joint are commenced. These movements at first should be very gentle, and one daily movement of flexion and extension only should be performed for the first few days. If no resultant reaction occurs freer manipulation is permissible, followed by massage and active movements, so that in from three to six weeks free normal use of the joint is established. In some instances, where complete asepsis has been obtained, even earlier restoration of function may be effected.

When persistent effusion is present and does not abate as a result of immobilization and extension, and even if there are no definite signs of severe sepsis, aspiration of the joint is indicated. This should be done with strictest aseptic precautions, preferably under nitrous oxide or general anæsthesia. The needle is inserted at some convenient spot well away from the wound and as much fluid as possible is withdrawn ; before

withdrawing the needle it is advisable to inject from a clean syringe about a drachm of eusol solution, so as to avoid infecting the soft parts surrounding the joint. The introduction of various antiseptic solutions into the joint after aspiration, such as formalin-glycerine, quinine hydrochloride (1 per cent.), flavine and ether, has been recommended, and good results are claimed therefrom, but these appear to do little or no good in cases of definitely established sepsis.

The fluid withdrawn must be examined both bacteriologically and cytologically; naked eye examination also often gives a rough indication of the degree of infection.

A straw-coloured or yellow fluid with flakes of lymph in it indicates usually a mild infection only. Turbidity of the fluid is a graver sign showing more advanced infection, and the formation of pus. Unhæmolysed blood, except that it is a good pabulum for organisms, is not of grave import; the presence of hæmolysed blood, on the other hand, is a danger sign, and is almost always due to an infection by the *Streptococcus hæmolyticus*.

The cytological examination of the fluid withdrawn gives information as to the nature, numbers and relative proportion of the cells in the exudate. Stained films should always be made, so as to determine the relative proportion of organisms to cells and the nature of the cells in the fluid.

Preponderance of mononuclear cells indicates a mild degree of infection, while excess of polymorphonuclear cells is of grave significance. Fragmentation of the cells, which take the stain badly, indicates senile degeneration or cytolysis due to toxins; the clinical signs together with an estimation of the numbers of organisms present will help to differentiate between these conditions.

A large number of organisms in each field gives evidence of a severe infection; a relatively small number, especially if staining badly and partly intracellular, shows that the infection is mild or has been overcome.

Identification of the organism by bacteriological examination is of great importance, as the prognosis and line of treatment depend largely on the nature of the infection. The organisms most commonly found are staphylococci, gas-forming organisms such as *Bacillus perfringens*, and streptococci both non-hæmolytic and hæmolytic. Of these the streptococci, especially if hæmolytic, are the most dangerous, and it is doubtful if a joint severely infected with a hæmolytic streptococcus can recover. The gas-forming organisms are less virulent, and

it is of interest to note that the formation of gas within the joint as a result of infections by this group is comparatively rare, and probably only occurs in a "closed" wound with hæmarthrosis. The staphylococci are the least virulent, and infections of this type are the most amenable to treatment. Where feasible the preparation of a vaccine from the infecting organism may be of value in the subsequent treatment of the case.

If in spite of adequate immobilization, aspiration, and so on, there is persistent pain, with pyrexia, rapid pulse, and dry tongue, it will be clear that there is a severe infection which is not yielding to treatment. In such cases little delay is justifiable, and no delay at all should be allowed if a hæmolytic streptococcus is present; the joint must be freely opened and the Carrel-Dakin treatment instituted, tubes being inserted into every recess of the joint. Many cases show prompt abatement of symptoms, but if this does not occur within thirty-six hours, amputation is indicated before the patient's condition has deteriorated too far. In some cases improvement occurs to a certain extent only, a chronic suppuration being established; this is generally found in cases where there has been extensive bone injury, and then the question of eradication of the sepsis by excision of the joint arises. In theory, excision, by allowing free drainage after removal of the grossly infected area, should be satisfactory; in practice, however, it has been found that, in the larger joints at any rate, the results are not very satisfactory, many deaths occurring from the shock of the operation or from the rapid onset of septicæmia or spreading local infection.

The selection of cases for excision requires considerable judgment, and the patient should remain under the care of one surgeon until the wound is closed and all sepsis has subsided. The question of excision is considered further in relation to individual joints.

Amputation is called for when conservative methods have failed and the patient's general condition is definitely deteriorating, the particular clinical signs being rapid pulse, pyrexia, loss of sleep, and a progressive anæmia. In fulminating cases, and where blood culture shows the presence of septicæmia, amputation is urgently necessary to save life. Secondary hæmorrhage and tracking of pus up and down the limb are also indications for amputation unless the sepsis can be controlled.

Treatment of Wounds of Individual Joints.

Hip-joint.—Wounds involving this joint are of great severity and associated with a very high mortality. Death may result

from shock and hæmorrhage soon after wounding, owing to the close relation of large blood-vessels to the joint and to the fact that an associated fracture of the femur or pelvis is commonly present. In the later stages a fatal result may occur from sepsis, the strong capsule of the joint tending to keep the septic exudate under tension and so increasing absorption; from gas gangrene owing to muscle injury; or from secondary hæmorrhage, particularly from vessels in the buttock.

In the forward area a Thomas' splint should be used for transport if the nature of the wound permits; failing this the joint should be immobilized as far as possible by means of a long Liston splint firmly applied.

At the casualty clearing station resuscitation is almost invariably needed before any operative interference can be undertaken. As soon as the patient's general condition allows, an X-ray examination is made to localize foreign bodies and to estimate the degree of bony injuries. Under anæsthesia the skin in the neighbourhood is shaved and cleansed, the wound track is excised *en masse* and the missile is removed if possible. Treatment of the joint cavity will depend largely on the exact nature of the injury and the extent of bony damage. "Groove" wounds of the anterior portion of the capsule should be sutured after excision of the wound; a Carrel-Dakin dressing is then applied to the surface wound and the limb is splinted with the wound left open. If the neck of the femur is comminuted or the head of the bone is much damaged it is advisable to remove the head and the fragments of the neck; this may be done through the original wound or through the usual incision for anterior excision of the joint. This excision is necessary in the first place because of the low vitality of the head and neck, as separation from the shaft of the bone is almost certain to result in necrosis, and also in order to provide free access to the joint for sterilizing purposes. If the head is left in position and septic arthritis occurs, tension within the joint, from its anatomical character, rapidly becomes very great, and severe toxæmia will result. After removal of the head of the bone, Carrel tubes are inserted and the wound is left open.

A suitable splint for all cases of this type is Jones' abduction splint (Fig. 1), which, if properly applied, allows complete immobilization and extension with good access to the wound area. In using this splint the most careful attention must be paid to the skin of the back, which must be kept absolutely clean and dry; this precaution is especially necessary when

the Carrel-Dakin treatment is being used. Patients with wounds of the hip joint travel badly, and they should, therefore, be retained in casualty clearing stations for at least seven days if local conditions allow. Where no abduction splint is available, a Thomas' splint should be fitted if the wounds allow it; failing this, the limb should be immobilized in the abducted position by means of a weight extension while the patient is in the casualty clearing station, a long Liston splint being applied for transport.

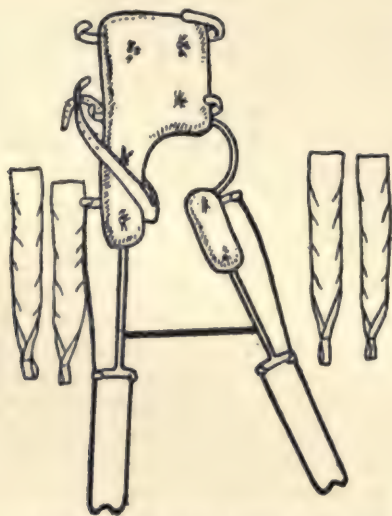


Fig. 1.—Modified abduction frame for pelvic wound; only to be used while wound discharges.

At the base, cases which have already been operated upon in the casualty clearing stations may be kept in the abduction frame if one has been applied, but they are better treated by extension and suspension, as if the case was one of high fracture of the femur. Where operation has not been performed it should be carried out on the lines indicated above. The advent of sepsis, indicated by pyrexia, rapid pulse, pain and fullness in Scarpa's triangle, makes it essential for the head of the bone to be removed in cases where this has not been done, and after excision the Carrel-Dakin method of treatment should be adopted.

Posterior drainage is rarely necessary as a separate measure and may be dangerous owing to spread of infection into the divided soft parts; in severe cases freer anterior access may

be obtained by transverse division of muscles. The only radical procedure available after excision has failed is amputation through the hip-joint, and this, in a patient already debilitated by septic absorption, generally proves fatal.

In cases which settle down satisfactorily secondary suture should be performed about ten days after arrival at the base, the limb being maintained for two or three months in a slightly abducted position. In less severe injuries, in which the head of the bone has not been excised, massage and movement may be tried in the hope of obtaining a movable joint.

The mortality of wounds of the hip-joint is estimated at 60 per cent. for all cases, and the end results in surviving patients are usually poor, grave loss of function and crippling generally resulting.

The Knee-joint.—The knee-joint is the largest joint in the body, and the large area of synovial membrane renders septic infection especially dangerous owing to the absorption of toxins. The joint is, roughly, divided into three pouches, namely—the subcrural pouch, the anterior pouch, and the posterior pouch. Of these the subcrural pouch may be divided partially by septa or folds of synovial membrane, the anterior pouch forms one irregular cavity, and the posterior pouch is divided into two portions by the posterior crucial ligament. All these pouches communicate with one another, so that infection, unless limited by the formation of adhesions, tends to become general. Of the bursæ in the neighbourhood of the joint, that under the semi-membranosus muscle communicates with the joint freely; of the others, those that do communicate do so by narrow openings which are readily sealed by inflammation.

In the earlier part of the war, wounds of the knee-joint were extremely fatal both to life and limb, but mainly owing to the work of Colonel Gray and the surgeons working with him rapid advances were made, so that in the later stages excellent results were obtained.

Wounds of the knee-joint may be divided into the following classes :—

Class A.—Without injury to bone—

- (1) Perforating.
- (2) Penetrating.

Class B.—With injury to femur, tibia, or patella—

- (1) Perforating.
- (2) Penetrating.

Class C.—With superadded injury to main vessels or nerves.

In the forward area, after sterilizing the skin and applying a dressing with a firm bandage, every case should be immobilized and extended in a Thomas' splint. The introduction of this splint for knee-joint cases was undoubtedly followed by very great improvement in after results.

In the casualty clearing station every case should be regarded as urgently requiring operation except where entry and exit are "leech-bite" in character and there is no bony injury; this latter type of case usually requires no operative interference other than possibly aspiration, and with suitable immobilization the patient can be evacuated direct to the base. Of the cases to be operated upon all should be X-rayed both for the localization of foreign bodies and to estimate the degree of bony injuries; the limb should not be removed from the splint until the patient is under the anæsthetic, so as to minimize the disturbance to the joint by rough movements.

In cases of Class A, treatment is carried out on the general lines already indicated, *i.e.*, clean excision of the wound area down to and including the capsule, removal of the missile, if necessary through a separate incision with clean instruments, irrigation of the joint with copious amounts of non-irritating fluid, and closure of the capsule with a further set of clean instruments. In the majority of cases the wound of the soft parts can also be closed with a tissue drain left in at one corner.

Closure of the synovial cavity, especially if the surface wound is extensive, may present considerable difficulty. This can, however, generally be overcome by mobilizing the sub-crural pouch by undercutting, for this gives a good deal of extra synovial membrane, or by the use of fascial grafts taken from the fascia lata of the thigh. The use of transplanted bursæ was advocated by the late Captain John Campbell, and was carried out successfully by him and Colonel Frankau in several cases, the bursæ employed being from the olecranon or prepatellar regions. If in spite of every effort it is impossible to close the capsule of the joint, even with skin flaps, the wound area should be firmly packed with gauze sterilized in liquid paraffin; this both fills up all dead spaces and helps to form protective adhesions.

In cases of Class B the initial stages of the operation are similar to those in Class A, but the question of treatment of the bony injury requires special consideration. Injuries to the femur are best treated by gouging away the bruised and therefore infected bone until free general oozing occurs; the surfaces are then dried with spirit and very lightly smeared

with B.I.P. In addition, in many cases, it is possible to exclude the injured portion of the bone from the general joint cavity by means of a flap of synovial membrane, and this should be done wherever it is feasible. Foreign bodies embedded in the end of the femur should be removed if easily accessible, otherwise it is safer to leave them. Unless there is extreme comminution, the prognosis in cases of joint wounds associated with injury to the femur is fairly good.

Where the tibia is injured the prognosis as regards saving the limb is grave. The soft cancellous tissue of the head of the tibia, if injured, is very liable to extensive septic infection, with secondary involvement of the joint, however well the initial treatment is carried out; further, it is hardly ever possible to exclude the injured area of bone from the joint cavity, as may be done in the case of the femur. Cases, therefore, of extensive comminution of the head of the tibia often require treatment by primary amputation.

In fractures of the patella the injury is usually severe, with great comminution; in such cases removal of the entire patella should be effected, the joint capsule being closed by mobilization of the subcrureal pouch and, if necessary, by bringing in flaps of the quadriceps extensor tendon. The results after complete removal of the patella are surprisingly good, the joint movements being but slightly affected. In minor injuries to the patella, each case must be treated on its own merits, and no hard and fast rules can be laid down.

The question of primary excision of the knee-joint in a casualty clearing station should never arise, as it may be fairly stated that a case requiring excision in the early stages is better treated by amputation.

In cases of Class C, where there is injury to the main vessels of the limb, or hopeless destruction of the popliteal nerves, amputation is usually necessary, owing to the severity of the local wound or to the onset of gangrene.

It will be seen, therefore, that amputation is required for severe comminution of the femur or tibia, especially the latter, for vascular injury, and in some cases of extensive injury to nerves; all other cases should be treated on conservative lines.

After operation an ample dressing should be firmly bandaged on, and the limb should be put up in a Thomas' splint with extension, the knee being slightly flexed.

It is advisable to retain patients with wounds of the knee-joint in the casualty clearing station for four or five days, or even

longer if local conditions allow. If longer retention is possible, and the wound is following an aseptic course, gentle movements of the knee-joint may be commenced before evacuation.

At the base, in cases where operation has already been performed, the splint is carefully readjusted and the patient is kept under observation, the particular points to be noted being pain, rapid pulse, pyrexia, and œdema of the leg. If the condition remains satisfactory, movements may be commenced after about a week; at first the gentlest movements only are permissible, and a single movement of flexion and extension each day is enough. If no reaction results these movements are increased, and repair is assisted by general massage of the limb. At the end of three weeks, full or nearly full movements should be obtainable, and the splint may be dispensed with; a walking calliper is advisable for the first few weeks when the patient begins to get about, especially if there has been much bony injury; this splint is removed for daily massage and exercises. When the wound of the soft parts has not been closed, secondary suture can be performed a few days after the arrival of the patient at the base, provided the local condition allows; early movement is necessarily slightly delayed in such cases.

One of the most satisfactory methods of obtaining early movements is by means of the ingenious apparatus devised by Major J. Everidge, shown in Fig. 2. This consists of a jointed Thomas' splint, with counterweights filled with sand; emptying of the sand allows movement of the knee-joint to a degree which may be varied to suit the local condition.

Where no operation has been performed before arrival at the base, the question of treatment depends largely on the nature of the injury and the length of time since the patient was wounded. In perforating wounds with minute entry and exit interference is usually unnecessary; the same applies to penetrating wounds where the metal fragment is obviously minute, even although removal of the missile at a later date may become necessary. In all other types of wound, provided the patients are received within thirty-six hours of wounding, treatment should be carried out on lines similar to those in casualty clearing stations. Great care must, however, be taken to avoid breaking down any definite protective adhesions, and it is usually advisable after closing the capsule to leave the wound of the soft parts open for five or six days. In cases received later than thirty-six hours after wounding, great judgment is required in deciding on the line of treatment to adopt. Where the infection is definitely localized, complete

immobilization, with extension and without any operative interference, will often give a satisfactory result even though there may be some impaired mobility of the limb. Any attempt at excision of the wound area and sterilization of the joint is fraught with great danger in these cases, owing to the likelihood of disseminating the infection through the entire joint cavity.

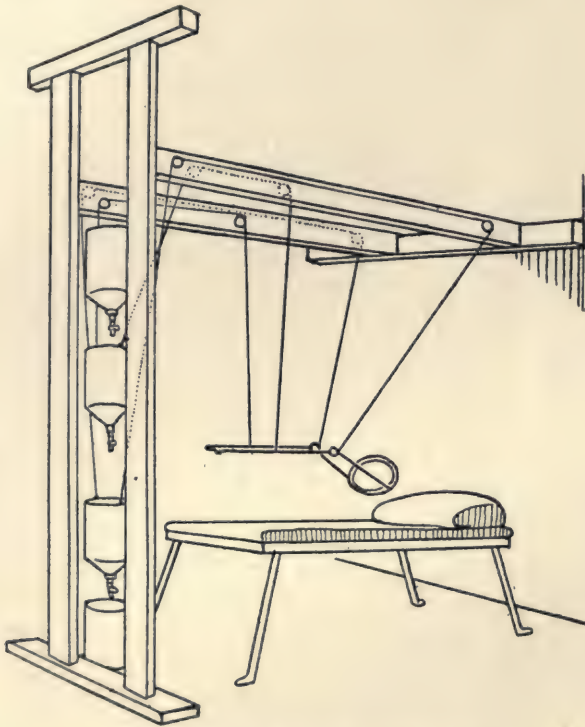


Fig. 2.—Major Everidge's apparatus.

The treatment of cases in which infection persists or occurs after operation, or is existent when the case comes under treatment, is best considered under two headings—namely, mild and severe infections.

In mild infections the main symptoms are pain, effusion, raised temperature and increased pulse-rate without any severe general symptoms. Such cases often settle down with satisfactory immobilization; if, however, the effusion persists, aspiration should be performed, the fluid obtained being

examined cytologically and bacteriologically. A single aspiration is often sufficient, and it is doubtful whether repeated aspirations are wise or of much use, and a consideration of the bacteriological and cytological findings is usually the best guide to further treatment. If aspiration fails to relieve symptoms it is unwise to wait for longer than thirty-six hours before performing an arthrotomy and washing out the joint. This may be followed by complete closure if the infection is a very mild one, but in many cases it is better to adopt the treatment by Carrel tubes. No delay at all is justifiable where the infective organism is a streptococcus, especially if it be of the hæmolytic variety.

Severe infections are nearly always complicated by bony injury, a factor which adds greatly to the danger. The only method likely to result in saving the limb is free arthrotomy and the introduction of Carrel tubes. To open the joint efficiently both anterior and posterior incisions are necessary; the anterior incisions are made three-quarters of an inch from the margins of the patella and extend from the upper part of the subcrureal pouch to the upper surface of the tibia. The posterior incisions are made by thrusting a pair of sinus forceps backwards into the popliteal space; on the inner side the point is just external to the inner head of the gastrocnemius, and on the outer side just internal to the outer head of that muscle. The skin is divided freely over the point of the forceps in each case, and the incision in the soft parts is cautiously extended up and down; if necessary the bellies of the muscle are also partly divided. Carrel tubes are then inserted as follows: two into the upper part of the subcrureal pouch, one on either side of the patella, one beneath the ligamentum patellæ, and two on either side leading down to the posterior incisions. Regular instillations of Dakin's solution are then commenced, the limb being carefully immobilized with extension on a Thomas' splint. The tubes must be changed every third day; they can usually be reduced in number by the sixth day and removed entirely about the tenth day. There is a great liability for secondary abscesses to form outside the joint; these should be freely opened and drained as soon as detected.

Failure of the symptoms to resolve, and the persistence of pain, pyrexia, rapid pulse, loss of appetite, and sleeplessness are indications for amputation, and this should be performed at once if septicæmia occurs. Disarticulation at the knee-joint by the guillotine method is the amputation associated with the least shock, but there is a great liability to secondary

hæmorrhage from the unprotected popliteal artery, and a secondary amputation is necessary in all cases. A supra-condylar amputation is therefore to be preferred when the patient's general condition permits.

Excision of the joint for severe sepsis was advocated at one period of the war; the results of this operation were, on the whole, unsatisfactory owing to the shock of the operation, the risk of spreading bone infection and the frequency of flail joints. Excision should be reserved, therefore, for continued low-grade infection where there is bony injury, and where for some reason it is highly important to preserve the limb.

At the end of the war the results from knee-joint wounds were exceedingly good; the mortality was low and amputations were rarely necessary. The functional results with early movement were greatly improved, and it was rare to get less than 40 per cent. in the range of movement even in a severe case.

Ankle-joint and Tarsus.—Wounds of the ankle-joint are commonly complicated by fracture of the tibia or fibula or of the astragalus; in more severe cases the os calcis may also be involved, together with the synovial cavities of the mid-tarsal joint. The tarsal bones are particularly liable to infection owing to their loose texture, and severe comminution of those bones is the rule.

In the forward area, apart from the application of an adequate dressing and a back splint with a foot-piece, no special line of treatment is indicated.

In the casualty clearing station, owing to the severe infection which is liable to follow wounds of the foot and ankle, early operative treatment is essential. After a preliminary X-ray examination, the leg and foot are thoroughly cleansed and the skin is sterilized with 2 per cent. picric acid solution in spirit; this sterilization of the skin is often extremely difficult and must be carefully carried out. The wounds of the soft parts are then excised and the bone injury investigated. In ankle-joint cases severe comminution of the astragalus is best treated by primary resection of the bone, preferably subperiosteally; fractures of the tibia and fibula are treated by removal of comminuted and bruised bone on conservative lines. Every endeavour should be made after cleansing the joint cavity to close the capsule; this is especially difficult when the astragalus has been removed, and if found impossible it is advisable to pack the cavity resulting from the excision with sterilized or paraffined gauze after very lightly smearing the surfaces with B.I.P.

In wounds of the tarsal bones and joints, severe comminution is best dealt with by subperiosteal resection, which can be freely performed except in the case of the os calcis. Resection of the latter bone cripples the foot to such an extent that the utmost conservatism must be practised. In every case where a tarsal bone is excised gauze packing is essential to obliterate the resulting cavity and to prevent the accumulation of blood-clot; the light application of B.I.P. to the cavity before packing is also of value.

Amputation, as a primary measure, should be reserved for severe comminution of the bones forming the ankle-joint, severe comminution of the os calcis, and extensive associated injuries to the soft parts of the sole of the foot. Where possible a Syme's amputation should be performed or, failing this, an amputation at the seat of election. It was found that if a Syme's amputation was performed the best result was obtained by packing the whole heel flap with gauze and performing a secondary suture after the lapse of three or four days.



Fig. 3.—Skeleton splint applied.

Immobilization of wounds of the ankle-joint and tarsus is a matter of great difficulty, and it may be said that for all but trivial injuries to the anterior part of the foot the back splint with a foot-piece is entirely inadequate except as a first aid measure. The following methods of immobilization are available :—

- (1) Jones' malleable iron "crab" splint for the ankle (Fig. 3). This splint allows free access to the part, and the ankle-joint can be fixed at any desired angle. The foot is slung from the toe-piece by means of strips of gauze and Sinclair's glue.
- (2) Sinclair's method with Thomas' knee splint. Here a slab of plaster or a piece of moulded poroplastic is glued to the sole of the foot; to the slab bands are attached which, being tied to the end of the splint, afford efficient extension and immobilization. This method is extremely satisfactory when the nature of the wound allows of its application, and should always be utilized where possible.

At the base, in cases uncomplicated by severe injury immobilization in a Jones' crab splint or by Sinclair's method is continued until the wounds are healed and all danger of sepsis is past. Gentle movements are then commenced, and later active remedial exercises. Where there has been extensive bony injury, and resection of some portion of the tarsus has been performed, it is essential to keep the foot inverted during treatment, and in case of injury to the ankle-joint, likely to be followed by ankylosis, in a position of slight dorsiflexion.

Extensive septic infection of the tarsal joints and bones can rarely be overcome so as to leave a useful foot, and in such cases removal, by Syme's amputation if possible, should be performed without much delay.

In severe septic infection of the ankle-joint a certain number of cases can be saved by excision of the astragalus followed by the Carrel-Dakin treatment, ankylosis being aimed at in a slightly dorsiflexed position ; if this fails, amputation through the leg is required.

The end-results of wounds of the ankle and tarsal joints were on the whole worse than in any other joint. The nature of the wounds, the extreme comminution of bone which was the rule, and the septic local conditions all militated against obtaining a clean and satisfactory result. Further, even after healing had occurred, so much pain and deformity often persisted that an amputation in many cases became a necessity in order to allow the patient to walk with ease and comfort.

Shoulder-joint. — The synovial cavity of the shoulder-joint consists of a single sac, and of all the large joints its arrangement is the least complicated, and therefore it is more easily sterilized than any other. The tendon of the long head of the biceps muscle is surrounded by a fold of the synovial membrane and the subscapularis bursæ communicates with the joint.

The joint is protected by the overhanging outer end of the shoulder-girdle, and owing, to this fact and the anatomical arrangement of the bones forming the joint, injuries without a bone lesion are rare.

In the forward area, after applying a dressing, the limb is immobilized by bandaging the arm to the trunk with a pad in the axilla ; a clove hitch should be applied to support the hand.

In the casualty clearing station X-ray examination is essential, both to determine the degree of injury and to localize the foreign body in penetrating wounds. It is important to remember that in the latter type of case the missile has not infrequently penetrated the thorax.

In simple through-and-through wounds by rifle bullet operative treatment is seldom necessary; local cleansing of the skin followed by immobilization is sufficient, and the case may be evacuated at once.

In other cases the wound of the soft parts is treated on the usual routine lines, care being taken to preserve if possible the biceps tendon as it crosses the joint. Extreme comminution of the head of the humerus may demand removal of portions of the bone, but this should be done sparingly, and formal excision is never advisable at this stage. After sterilization of the joint cavity by free irrigation the capsule should be closed by suture if possible; in extensive wounds, especially on the outer aspect of the joint, this may be a matter of difficulty, but by the use of muscle or skin flaps the joint cavity can usually be partly if not completely shut off. If complete closure is not possible the wound should be lightly packed with gauze, either dry or soaked in flavine or liquid paraffin.



Fig. 4.—Humerus extension splint, wooden pattern.



Fig. 4A.—Humerus extension splint, metal adjustable pattern.

Slighter cases with no bone injury travel well with the arm bandaged to the side with a sling supporting the wrist and hand. More severe cases require immobilization with extension, which can be obtained by using a straight Thomas' splint,* if the wounds permit, a Hey Groves' humerus splint or a Campbell splint (Figs. 4 and 5).

Extreme comminution of the upper end of the humerus, very severe injury to the soft parts, or division of main vessels and nerves demands disarticulation at the shoulder-joint by such flaps as are available.

Fixation of the joint in an abducted position should be effected at the base as soon as possible; this position gives the maximum of rest to the joint and also is the best position

* See Vol. I, Chap. X, Fig. 4.

in case of ankylosis if this should occur. The most satisfactory pattern of splint is that devised by Captain Campbell (Fig. 5). In this splint extension is taken from the upper arm so as to allow movement at the elbow-joint. The position of fixation is important ; as a rule the arm should be abducted sixty degrees with the elbow slightly in front of the coronal plane and with a few degrees of internal rotation. Ankylosis in this position gives the maximum of mobility through the scapula movements.

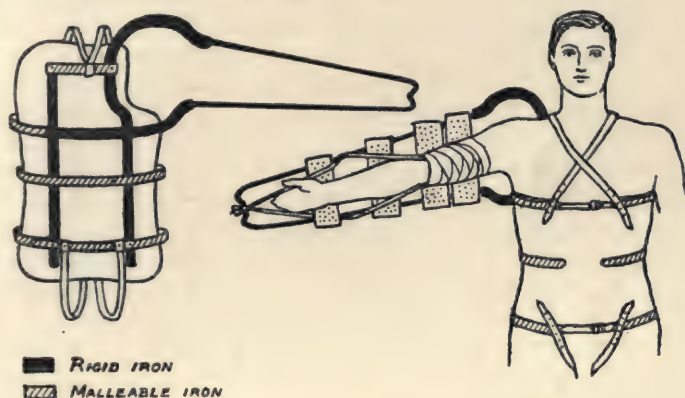


Fig. 5.—Campbell's abduction splint.

In cases remaining aseptic after the primary operation, or where operative interference has not been deemed necessary, movements should be commenced as soon as the wounds are healed in uncomplicated cases, and after about three weeks where there is bone injury ; these movements must be gentle at first and rotation should always be performed in addition to abduction. The position of abduction should be maintained for about three weeks in uncomplicated cases, but for a considerably longer period where there has been bone injury.

Septic cases, if the infection is not severe, often settle down with adequate extension and immobilization. Persistence of symptoms demands the re-opening of the wound, with a secondary posterior incision if necessary, and the insertion of Carrel tubes ; sterilization can almost always be obtained by this method.

In prolonged suppuration secondary excision may be necessary, but the risk of an acute osteomyelitis of the shaft of the humerus should be remembered and excision should be avoided if possible.

Disarticulation at the shoulder-joint is required as a life-saving measure for spreading bone infection, severe toxæmia, and secondary hæmorrhage.

Elbow-joint.—The synovial cavity of the elbow-joint is complicated in its arrangement and is partly divided into an anterior and a posterior compartment by the bones forming the joint. The superior radio-ulnar joint is an annexe of the main sac and communicates freely with it.

Wounds of the elbow-joint are almost always associated with a bony injury and the close association of the brachial artery and large nerve trunks makes injury to these structures not uncommon.

In the forward area the joint should be immobilized on an internal angular or Clark's splint after the application of a suitable dressing.

At the casualty clearing station careful investigation must be made, and any nerve injury noted in detail on the field medical card. An X-ray photograph should be taken to localize any retained missile and to estimate the degree of bony injury. At operation the wounds of the soft parts are excised and the ends of the nerves if divided are identified for suture at the close of the operation. Severely comminuted bone is best treated by removal of detached fragments, but this should be done conservatively and every endeavour must be made to preserve the olecranon process. No formal excision of the joint is justifiable at this stage.

For effective irrigation of the joint cavity a second incision on the antero- or postero-lateral aspect of the joint is usually required, and this can be made without hesitation provided clean instruments are used for the purpose. The joint cavity is then shut off by suture of the synovial membrane and capsule, or in cases of extensive destruction of the soft parts by sliding in skin and fascial flaps. Primary suture of the soft parts can usually be performed in small wounds, but in more extensive wounds this is best delayed.

For transport, the limb is extended and immobilized on a Thomas' splint with the hand fully supinated.

At the base if the local wound condition is satisfactory the Thomas' splint with extension is retained for the first few days, secondary suture being performed where required. As soon as the wounds are healed the arm is put up under an anæsthetic in extreme flexion without a splint and retained in this position for two days. Gentle movements of flexion and extension—at first once only in each direction on each day—

are then commenced and gradually increased provided no reaction occurs.

Where the joint is uninfected, the arm should on no account be retained in a straight Thomas' splint for more than fourteen days, owing to the danger of greatly impairing its movements. Much disability was often caused through these splints being kept on too long in patients who should have been released from the extension within a few days of arrival at a base hospital. Where there is a large granulating surface wound the position of extreme flexion may be impossible; if this is so a bent Thomas' splint with a hinge at the elbow should be fitted. This splint allows daily movement of the joint and the movements, in addition to keeping the joint free, will overcome any crippling effects of the peri-articular scar tissue.

If the joint is septic arthrotomy by lateral incisions is indicated, followed by the application of a Carrel-Dakin dressing, the limb being maintained with extension in a Thomas' splint. By this method the majority of cases clear up in a comparatively short time and at the earliest possible moment the limb should be placed in the best position for ankylosis in a Jones' interrupted arm splint. (Fig. 6.)



Fig. 6.—Elbow splint applied.

Severe sepsis with extensive necrosis of bone, signs of absorption, and other complications requires more radical treatment and free drainage. To achieve this a partial subperiosteal resection should be performed, to include the articular head of the radius so as to allow subsequent movements of pronation and supination. After excision the limb is treated by the Carrel-Dakin method on a

straight Thomas' splint with extension until the sepsis has abated ; it is then put up on a Jones' interrupted arm splint with the elbow-joint flexed to a little less than a right angle and the hand midway between pronation and supination.

A certain number of cases of resection will recover with some movement at the elbow-joint, and an attempt should be made to achieve this end by gentle movements as soon as the local condition allows. If, however, even the gentlest movement is followed by reaction, the joint should be allowed to ankylose in the position indicated above. Ankylosis should also be aimed at where extensive removal of bone has been necessary, owing to the risk of a flail joint otherwise resulting.

By these methods the most extensive injuries to the elbow joint can often be brought to a satisfactory conclusion. Amputation should be reserved for extensive spreading sepsis with involvement of bone, and for cases in which, in addition to extensive local injury, irreparable nerve lesions make the hand useless.

Wrist-joint and Carpus. — The wrist-joint is a simple diarthrodial joint which in many cases communicates with the inferior radio-ulnar joint, from which it is separated by a fibro-cartilage. The carpal joints are extremely complex ; one point of particular importance is that the joint between the first metacarpal bone and the trapezium is formed of an isolated synovial membrane so that, if possible, in a resection of the carpus the trapezium should be spared. The radial and ulnar arteries and the median and ulnar nerves are all in close relation to the wrist joint and are very liable to injury.

Wounds of the wrist-joint without bony injury are uncommon ; extensive comminution of the lower end of the radius often occurs.

In the forward area it is sufficient to apply a simple dressing with a flat splint to immobilize the hand and forearm after arresting hæmorrhage, which may be severe.

At the casualty clearing station simple perforating wounds require nothing further than redressing after sterilizing the skin and immobilizing on a splint. More extensive wounds are treated on the ordinary routine lines ; comminuted and bruised bone is removed, care being taken to preserve as much as possible of the lower ends of the radius and ulnar if they have been damaged. Divided nerves should be sutured if possible ; tendon injuries are best left for repair at a later stage unless the wound is a comparatively slight one.

Closure of the joint cavity after sterilization in the case of

the wrist-joint is rarely possible, hardly ever in the case of the carpal joints. The wounds should, therefore, be lightly packed with gauze after applying a thin film of B.I.P., or a Carrel-Dakin dressing may be utilized.

Splinting with a straight, flat splint immobilizing the forearm and hand is all that is necessary at this stage for purposes of transport.

At the base the simple perforating wounds which remain uninfected require no special treatment apart from early movement and exercises. More severe wounds likely to be followed by partial or complete ankylosis should be put up on a "cock-up" splint so as to keep the wrist in dorsiflexion; this splint may be of wood or of iron (Fig. 7). Severe sepsis will require immobilization with extension, which may be obtained in a Thomas' splint, the extension being obtained by strips of gauze glued to the dorsal and palmar aspect of the hand.



Fig. 7.—Skeleton hyper-extension hand splint.



Fig. 7A.—Skeleton hyper-extension hand splint applied.

Continued sepsis may necessitate the removal of further damaged bone by sub-periosteal resection. Complete disorganization of the wrist-joint and carpus, especially if there is extensive injury to tendons and nerves, demands amputation.

As soon as the sepsis has abated the hand should be put up in the dorsiflexed position so as to retain as much grip as possible.

Special care must be taken to prevent deviation of the hand if there has been extensive injury to one of the bones of the forearm, the other remaining uninjured or only slightly damaged.

Ankylosis.

In all joint injuries likely to be followed by ankylosis it is important to fix the joint in such a position that its usefulness

afterwards is impaired to the least possible extent. The position has been indicated in describing the treatment of each joint, but the main points may be summarized as follows.

Hip-joint.—The best position of ankylosis is with the thigh in full extension, and abducted about 10 deg. from the straight line with the foot pointing directly forwards, *i.e.*, with no rotation of the thigh outwards. This external rotation very readily occurs and must be carefully guarded against.

Knee-joint.—The position of election is that of extension, but very slight flexion may be permitted. During convalescence two points require careful attention, first, the occurrence of *genu recurvatum*, which may result from softening of the ligaments, and secondly a constant tendency for the tibia to drop back behind the line of the femur and to rotate outwards. Both these deformities can be overcome by careful splinting or plaster work.

Ankle-joint.—The foot should be slightly dorsiflexed with the sole slightly inverted, as this position allows of easier walking and provides a stronger foot. Extension of the foot and eversion of the sole are both to be avoided.

Tarsal Joints.—Endeavours should be made to preserve or exaggerate the arches of the foot and to procure inversion of the sole to a small degree.

Shoulder-joint.—The arm should be abducted from the side to about 60 deg. while the scapula remains in its normal position; the elbow should be just in front of the coronal plane of the body and a very slight internal rotation of the humerus is an advantage.

Ankylosis in this position allows free movement of abduction through the scapula movements and gives an extremely useful limb.

Elbow-joint.—The best position for the majority of patients is just less than a right angle, that is about 75 deg. This allows of feeding, brushing the hair and so on with little difficulty.

If both elbows are injured the right should be ankylosed at 75 deg. and the left at about 110 deg.

If the superior radio-ulnar joint is involved the hand should be fixed at a point midway between pronation and supination.

Wrist-joint.—Dorsiflexion is absolutely essential in order to allow a useful finger grip. With ankylosis in the straight line the hand grip is greatly impaired, and in palmar flexion it is entirely abolished.

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CHAPTER X.

FRACTURES OF THE UPPER EXTREMITY.

THE general principles of treatment of the wound in gunshot fractures of the upper extremity differ but little from those of similar injuries in other parts of the body. Several points, however, require brief notice.

First, as regards the treatment of the wound area, excision of the wound track is essential as in all other wounds. In the forearm this may be a matter of considerable difficulty, owing to the close apposition of the tendons and soft parts to the bones and the limited space available, a difficulty which can only be overcome by free lateral incisions. Primary suture or delayed primary suture can be performed in a large number of cases provided the initial treatment has been early and thorough, and it is of interest to note that one of the first compound fractures to be treated by primary suture was a case of fractured radius and ulna successfully treated in June 1916.

Secondly, there need not be great hesitation in removing loose bone fragments in the case of the shaft of the humerus, provided that really good end-to-end apposition is obtained, since very little disability results from shortening of the upper arm in contrast to shortening of the thigh. In severe comminution of the radius or ulna more conservative methods are necessary, as great deformity results from the shortening of one bone, the other being intact. As a matter of experience it may be noted that attempted conservation of fragments of the radius and ulna very often results in necrosis and non-union, although, if this occurs, filling of the gap by a bone graft at a later date has given many brilliant results.

Thirdly, associated nerve lesions are relatively more frequent in the upper than in the lower extremity, and are of even greater importance. Their early recognition and treatment are essential.

Lastly, as regards amputation, the most conservative attitude must be adopted in dealing with upper extremity injuries, since even the worst natural limb, provided some grasp is possible, is better than the best artificial limb.

The evolution of splints for fractures of the upper extremity is of historical interest. At the commencement of the war the standard splints available in the forward area were as follows :—

- (a) Internal angular, fixed and movable.
- (b) Anterior angular, fixed and movable.
- (c) Straight forearm splints, wood and wire.
- (d) Carr's splints.

These splints, while being fairly adequate for the majority of simple fractures, were soon found to be inefficient in severe gunshot fractures, as they had to be removed in order to dress the wounds, and in many cases provided insufficient immobilization and support.

Early in 1915 a wood and wire splint for fractures of the humerus was introduced by Captain Colin Clark. This splint was a modification of the wood internal angular splint, the upper limb being replaced by an inverted **U** of stout iron wire covered with rubber. The curve of the **U** rested on the top of the shoulder, the limbs of the **U** lying parallel to the upper arm but not in contact with it. This splint allowed good access for dressings without removing the splint, and gave good immobilization. It did not, however, provide extension, and it was liable to slip from the shoulder when the patient was in bed. Cowell and Page both devised "cage" splints of aluminium strip for application to the outer aspect of the arm, allowing easy access to the wound. Both these splints were distinct advances, but did not provide adequate extension. In the spring of 1915 Clark's second arm splint, an internal angular splint of an adjustable pattern with a posterior shelf on the upper limb to support the fracture, was introduced, and soon became a standard splint for the first aid treatment of fractures of the humerus. It was especially valuable where roads were bad and distances great, owing to the additional support provided for the humerus. All these improved splints were evolved on the Western front, but meanwhile in England, in 1915, Sir Robert Jones had drawn attention to the applicability of the Thomas' splint with various modifications for fractures of the upper extremity, and had also shown the value of the interrupted elbow splint and the "cock up" splint for wounds of the elbow and wrist joints respectively.* All these splints became standard from forward area to base, and remained so, with additions and modifications, to the close of hostilities.

* Chapter IX, Figs. 6 and 7.

Several simple and ingenious splints, designed to provide suspension with extension and allowing free access to the injured limb for dressings or massage, were devised by Hey Groves in 1915-16. These splints were for the most part better adapted for treatment of cases at the base hospitals and during convalescence, and proved of great value.*

Lastly, the method of extension and suspension by counter-weights from a Balkan frame was found to be particularly applicable to severe septic wounds, especially if there were injuries to other parts.

The fractures under consideration fall into four groups, involving (a) the shoulder girdle, (b) the upper arm, (c) the forearm, and (d) the bones of the hand.

Fractures involving the Shoulder Girdle.

Fractures of the Clavicle.—These fractures came under treatment comparatively rarely, as they were necessarily severe, and frequently proved fatal owing to the close proximity of great vessels. Extreme comminution was the rule; associated wounds of the lung or injuries to the brachial plexus were not uncommon, and in each case made the treatment more difficult.

In the front area a suitable dressing was applied, and the arm was supported by means of a sling or by bandaging it to the side after a pad had been placed in the axilla.

In the casualty clearing station, cases uncomplicated by lung injuries should be X-rayed, a careful investigation should be made to identify any associated brachial plexus lesion, and the result of this examination should be fully recorded in the field medical card. The wound area is then excised, and irretrievably damaged portions of bone are removed; great care is necessary in removing bone owing to the proximity of the dome of the pleura and the subclavian vein, both of which are liable to injury. Occasionally sharp spicules of bone are found to have been driven into the subclavian vein, necessitating ligation of that vessel. Tears of the pleura should be repaired with fine catgut sutures. Early cases adequately treated do well with primary suture, the patient being retained for some days in the casualty clearing station. Where circumstances do not allow of primary suture the whole wound area is left open and is lightly filled with dry gauze or gauze soaked in sterile liquid paraffin. If the wound permits, Sayre's method is very satisfactory for retaining the fragments in position; if this is not possible the arm should be bandaged

* Chapter IX, Fig. 4.

to the side with a pad in the axilla, the wrist being supported by a clove hitch.

Treatment of injuries to the brachial plexus is best postponed till the arrival of the patient at the base, any deformity such as wrist-drop being corrected by means of a suitable splint.

Where there is an associated lung injury the treatment of this condition necessarily takes first place, and little can be done for the bony injury beyond sterilization of the wound area.

At the base, Sayre's or Hey Groves' methods of fixation are suitable in cases in which satisfactory healing of the wound has occurred after primary or secondary suture. Septic cases should be confined to bed, the patient lying flat on his back with the forearm supported by a sling, and the wound area treated by the Carrel-Dakin method. As soon as the wound is sterile secondary suture is performed and the limb is put up by Sayre's or other method. Non-union is comparatively rare, and extremely good functional results are usually obtained in spite of considerable local deformity.

Fractures of the Scapula.—Wounds of the scapula are of comparatively frequent occurrence, being often caused by shrapnel bullets and fragments of shell case. An associated wound of the thorax is not uncommon, and should always be suspected.

In the forward area no special retentive apparatus other than a sling is necessary after application of a dressing.

In the casualty clearing station examination of the chest and X-ray investigation are essential to exclude a penetrating wound of the lung and to localize the foreign body if retained. Under general anaesthesia the wound track is excised, special attention being paid to lacerated muscle, which in this region is very subject to gas infection. Where the body of the scapula is injured there is usually very considerable fissuring of the thin bone forming it; these fissures rarely extend into the neck of the bone and therefore are unlikely to extend into the shoulder joint. The missile, if retained, is usually embedded in the back muscles deep to the scapula, and is very difficult of access without extensive removal of bone. This may be done without hesitation as long as the borders of the bone are respected. Injuries to the spine of the scapula are usually associated with groove wounds of the back; the severity of the injury may vary from a simple notching to separation of almost the entire spine. A conservative line of treatment of the injured bone should be adopted as far as possible, the

acromion process being specially respected. Wounds of the spine and body of the scapula are generally suitable for primary suture, and this should be carried out whenever possible. No splint is required, but a sling should be applied to support the weight of the arm or the arm may be bandaged to the side.

Wounds of the neck of the scapula are liable to involve the shoulder joint by extension outwards of the fracture. If this is the case the limb after suitable treatment of the wound should be immobilized with extension on an abduction splint.* Failing this splint, the arm should be firmly bandaged to the side, the hand being supported by a clove hitch.

At the base, in the case of fractures of the spine and body of the scapula, gentle movements of the shoulder joint should be commenced as soon as the wound has healed, so as to prevent any limitation of movement. As soon as the local condition allows more active exercises are commenced, and in the majority of cases good functional results are to be obtained. Similar treatment is carried out in fractures of the neck of the bone if the shoulder joint is not involved. It should, however, be noted that, union in these fractures being slow, resumption of active movements is necessarily delayed.

Where the shoulder joint is involved treatment should be on the lines indicated on page 318. Good functional results with good movement can usually be obtained in these cases, provided the infection has been overcome by thorough initial treatment of the wound.

Fractures of the Humerus involving the Shoulder-joint.—These injuries are not infrequently complicated by associated injuries to the chest, and special attention should be paid to this possibility particularly if there is only an entrance wound.

In the forward area early treatment differs in no way from that of injuries of the upper third of the shaft. At the casualty clearing station the usual treatment for wounds of joints is necessary, namely, excision of the wound track, cleansing of the joint cavity and closure of the capsule. Closure of the capsule often presents great difficulties owing to the extensive destruction of soft parts; fascial flaps from the neighbourhood can often be obtained, however, and satisfactorily utilized. The treatment of the head of the bone requires careful consideration. As far as possible anything in the nature of a formal excision is to be avoided; shattered and bruised fragments may be removed, particularly if they are portions of cartilage-covered end of the bone. Experience has shown that even

* See Chapter IX, Fig. 5.

with extreme comminution good end results are obtainable with conservative methods.

For transport to the base the Thomas' arm splint with extension is suitable where the nature of the wound allows of its being used. Failing this splint, a Hey Groves' splint can often be applied or, if this is not available, the arm should be bandaged to the side with a pad in the axilla and a sling support for the hand.

At the base fixation of the arm in an abducted position with extension should be effected as early as possible. One of the best types of splint, if not the best, is that devised by Campbell.* It is important to remember that extension in this splint should be taken from the upper arm so as to allow of movements of the elbow joint. The position of fixation is important; as a rule the arm should be abducted 60° with the elbow slightly in front of the coronal plane and with a few degrees of external rotation. Ankylosis occurring in this position gives the maximum of mobility through the scapular movements. The majority of cases even if badly infected settle down with this method of treatment and secondary interference, provided an adequate initial operation has been performed, is rare. The advent of severe sepsis necessitates free opening up of the joint cavity with removal of necrosing bone and drainage of all pus pockets. The Carrel method of disinfection of the wound should be instituted at the same time, and many of the most desperate cases can be brought to a satisfactory conclusion by these means. Severe osteomyelitis with spreading periarticular suppuration demands disarticulation at the shoulder joint as a life-saving measure.†

Fractures involving the Upper Arm.

Fractures of the Humerus.—In gunshot fractures of the shaft of the humerus there is, as a rule, very severe comminution of bone with extensive laceration of muscle and in perforating wounds explosive effects at the exit. Occasionally, when the missile is a machine-gun or rifle bullet, entrance and exit may both be quite small with nevertheless extreme comminution of the shaft; bullet wounds of the head of the bone may produce simple perforations with no comminution and without causing any grave damage or infection.

Fractures of the extremities of the bone may involve the shoulder or elbow joints. Large nerve trunks, especially

* See Chapter IX, Fig. 5. † See also Chapter IX.

that of the musculo-spiral nerve, are very liable to injury, and wounds of the brachial artery are not at all uncommon.

In the front area, after a dressing has been applied, the arm is bandaged to the side, the wrist being supported by means of a clove hitch of bandage passing round the neck. This method is eminently satisfactory for fractures of the upper two-thirds and in most instances no splint need be applied at main dressing stations. For fractures of the lower third a splint is generally necessary, and the type which has been found most satisfactory is the Clark's arm splint depicted in Fig. 1.

In casualty clearing stations, careful investigation should be made for nerve injuries before the patient is anæsthetized, and the results should be recorded at once in the field medical card. After the usual routine wound treatment the arm is put up in extension in a Thomas' arm splint with the hand fully supinated.

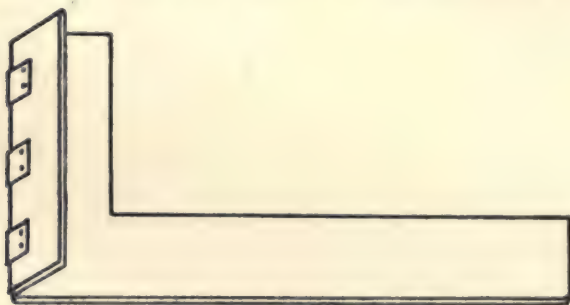


Fig. 1.—Clark's arm splint.

This splint is suitable for the initial treatment of all fractures of the upper arm with the exception of severe wounds involving the axilla or deltoid region. It must be clearly understood, however, that in fractures of the lower third of the humerus this type of splint does not give a satisfactory alignment owing to the tilting forward of the lower fragment; its use therefore must only be regarded as a temporary expedient. For ease in transport the Thomas' arm splint with a swivel ring is valuable, though it does not give so satisfactory an extension as the fixed ring splint and therefore should be avoided if possible. Where wounds of the axilla or deltoid region prevent the application of a Thomas' splint, the most suitable method for transport to the base is the pad in the axilla with the arm bandaged to the side and the wrist supported by a clove hitch. The most conservative attitude should be adopted in dealing

with fractures of the shaft of the humerus. Extensive loss of bone and extreme comminution are no bar to an ultimately successful result provided efficient sterilization of the wound area is obtained. Amputation should be reserved for cases in which in addition to the bone injury there is extensive muscle destruction and the main vessels and nerves are destroyed.

At the base, when the wound is satisfactory and primary or secondary suture has succeeded, the limb should be in most cases removed from the straight Thomas' splint after ten days and put up on a bent Thomas' splint (Fig. 2) with a joint at the elbow or a Hey Groves' splint. These splints allow free access for dressings, and at the same time give extension and permit of movements of the elbow joint. The application of the flexed type of splint is essential in fractures of the lower

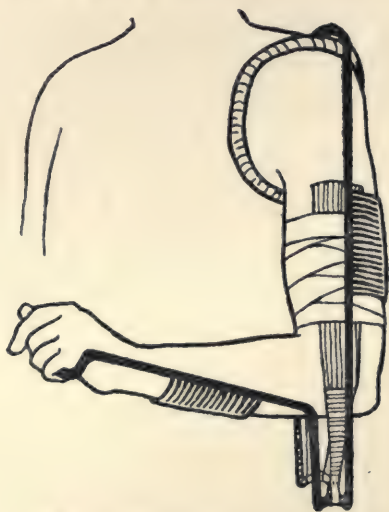


Fig. 2.—Bent Thomas' splint.

third of the humerus, in order to bring the fragments into proper alignment, for which purpose flexion to 110° is usually necessary. In fractures of the upper third abduction of the arm is required in order to obtain proper alignment of the fragments; this abduction is best obtained at first by the use of the straight Thomas' splint, with the extension taken from the lower part of the upper arm above the elbow so as to allow movements of the elbow joint. In the later stages Middel-dorpf's triangle, or some modification of this apparatus, is satisfactory.

In unsatisfactory cases, in which sepsis is present, it is advisable to sling the limb from a Balkan frame and attempt to procure sterilization of the wound by the Carrel-Dakin method. The majority of wounds of the arm will clear up with this method provided there is no pocketing of pus and no gross bone infection.

In all cases, as soon as the wounds permit, careful passive movements of the shoulder and elbow should be undertaken and the patient should be encouraged to move his wrist and fingers from the start. Massage can usually be commenced with safety about two weeks after the wound has healed and greatly assists in the consolidation of the fracture.

Fractures involving the Elbow-joint.—Any of the bones forming the joint may be involved and in many instances more than one is affected. The principles and details of treatment of such fractures are those already described in the preceding chapter in connection with wounds of the elbow joint.

Fractures involving the Forearm.

Fractures of the Bones of the Forearm.—The injury may involve one or both bones, and in most cases extreme comminution is the rule. Associated injuries to nerves are very liable to occur and this possibility should never be overlooked.

In the forward area, after application of a dressing, the limb is immobilized in a straight splint and supported by a sling. The splint applied should be long enough to extend from the olecranon process to the tips of the fingers, and should be as wide as the widest portion of the arm.

In the casualty clearing station, after investigating the condition of nerves, an anæsthetic is given, and the wound treated by excision and cleansing; useless fragments of bone are removed, especially those which have been driven into surrounding muscle, but care should be taken to preserve all viable fragments. Divided nerves should be sutured, and the fact should be recorded on the field medical card. Where possible, primary suture of the wound should be performed; failing this the wound area should be very lightly filled with sterile gauze or gauze soaked in flavine solution or paraffin. The limb should be put up in extreme supination with extension in a straight Thomas' splint, or in a bent Thomas' splint in a similar position, with the elbow fixed to the angle of the splint by means of strapping. The former method is the better, but cannot always be used, as the patient must necessarily be transported lying down.

At the base in satisfactory cases the limb is kept on the straight Thomas' splint for fourteen days, secondary suture where required being performed on the sixth to eighth day; during this time the patient is encouraged to move his fingers so as to ensure freedom of tendons. On the fourteenth day the limb is taken off the straight splint, and a bent Thomas' splint with a joint at the elbow or a Hey Groves' splint is applied; the fully supinated position is maintained, and extension is necessary for a further three weeks. Careful daily movements of wrist and elbow should be commenced as soon as the wound is soundly healed. At the end of five or six weeks, if consolidation has occurred, the splint is removed and the limb, still in the supinated position, is supported on a leather or papier mâché trough splint. Massage and more active movements may be undertaken at this stage.

Where sepsis occurs, sterilization by the Carrel method is the most efficient method, the limb being necessarily maintained for a longer period in the straight or bent Thomas' splint.

Full supination is necessary throughout the treatment to prevent cross-union and to diminish the impairment of movements of pronation and supination, which are very liable to occur if the limb is put up in any other position.

Special precautions should be taken to prevent deviation of the hand from its proper alignment in cases in which there has been considerable loss of substance of either radius or ulna, as this deviation is particularly difficult to overcome when once established.

Fractures of the Bones of the Hand.

These may be divided into three groups—

- (a) Wounds of the carpus,
- (b) Wounds of the metacarpus,
- (c) Wounds of the digits.

In the forward area the first two groups are characterized by a tendency to severe hæmorrhage and by the existence of pain which is often very severe. The hæmorrhage can usually be controlled by firm bandaging over a graduated dressing; failing this it is often possible to catch the bleeding point with artery forceps. Continuance of hæmorrhage will necessitate operation in the main dressing station; no wound of the hand should ever be sent to a casualty clearing station with the hæmorrhage controlled by a tourniquet.

Simple flat splints to immobilize the hand and forearm add greatly to the patients' comfort.

Wounds of the Carpus.—Wounds of the carpus are found to vary from a simple perforation to extensive and often "explosive" wounds destroying tendons and nerves and frequently involving the wrist joint. In the casualty clearing station simple perforating wounds by bullets rarely require anything further than a simple dressing and a sling. Penetrating wounds with a retained missile should be explored after X-ray examination in order to remove the foreign body and to cleanse the wound area. The complicated nature of the synovial cavity of the carpus makes effective sterilization difficult once sepsis has commenced, and for this reason meticulous care is needed in dealing with the wound area. There need be no hesitation in removing damaged carpal bones as they are very liable to necrose.

In more serious cases in which there is an explosive exit wound, attention should be concentrated on the excision of the infected tissues; in the majority of cases it is inadvisable to attempt any repair of tendons as this can be done more satisfactorily at a later date. Injury to nerves should be treated where possible by suture, as even if this fails it makes further treatment at the base easier. Damaged carpal bones should be excised, preferably subperiosteally; the resulting cavity and the entire wound area are then lightly smeared with B.I.P. and packed with dry or paraffinized gauze.

Wounds involving the radio-carpal joint are treated on the same lines, but if possible the capsule of the joint is closed by sutures, a proceeding which presents great difficulty in most cases. The most conservative line of treatment should be adopted and amputation should be reserved for hopelessly damaged hands.

Splinting of the hand and forearm is essential, and for this purpose a straight flat splint extending from the bases of the proximal phalanges to the elbow joint is quite adequate at this stage. The splint is applied to the flexor aspect of the limb and the fingers should be flexed over the end of it.

At the base the simpler uninfected wounds require no special treatment other than careful movements increasing in degree as soon as the wounds have healed. Where there is obvious infection, immobilization with extension is necessary. This can be obtained most easily on a Thomas' arm splint, extension being taken from the dorsum and palm of the hand by means of strips of gauze attached by glue; extension should never

be taken from the fingers, if it can be avoided, owing to the risk of adhesions.

If sepsis persists and is not localized it may be necessary to remove the carpus subperiosteally, if possible preserving the trapezium which has a separate joint cavity for the thumb. As soon as the sepsis has settled down it is essential to put the hand up in a Jones' "cock-up" splint, since a straight ankylosed wrist joint allows of practically no grip.

In the extensive explosive wounds sterilization can often be facilitated by continuous saline or eusol baths. As soon as the wound is clean, plastic operation on tendons, etc., should be performed and the wound area should be covered in by sliding flaps or grafts so as to lessen the amount of cicatricial tissue. The after treatment is on the lines indicated above.

Wounds of the Metacarpus.—In the casualty clearing station these wounds require treatment on the usual lines so as to ensure rapid healing. The injured bone must be treated conservatively and every attempt should be made to cover in exposed tendons.

At the base, tendon repair should be effected when possible ; irreparable damage to tendons may necessitate subsequent removal of a contracted and useless finger. Early movements and exercises are necessary as soon as the wounds are healed to prevent loss of function due to adhesions.

Wounds of the Digits.—One of the most remarkable of the effects that may be produced by the modern high velocity bullet is the simple perforating wound of a phalanx with no comminution and no gross injury to tendons. This type of injury has been observed in both battle casualties and self-inflicted wounds so that it may clearly occur at any range ; such cases only require a simple dressing, and a few weeks' rest and no impairment of function is the rule.

Other cases, with comminution of bone and injury to tendon, require at the initial operation the ordinary routine treatment of wounds, repair of tendons, etc., where the nature of the injury allows conservative treatment. The greatest care should be taken to preserve as much as possible of the thumb and index finger, and primary amputation should only be resorted to in hopelessly damaged fingers.

In the case of injuries to single digits immobilization can be effected by strips of fine mesh wire gauze sterilized and incorporated in the dressings. Multiple injuries require a splint which controls the whole hand. In all cases as soon as the wounds are healed attention must be directed to moving the

uninjured fingers to prevent adhesions, and as soon as the bone condition allows this should also apply to the injured digits. In those cases where an injured finger with fractured bone becomes badly septic, early amputation should be performed. Such a finger if ultimately saved is generally of little use, and efforts to save it, if prolonged over many weeks, are liable to leave a stiffened and damaged hand. At one time during the war such a result was of common occurrence.

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CHAPTER XI.

FRACTURES OF THE LOWER EXTREMITY

Fractures of the Femur.

GUNSHOT wounds causing fracture of the femur were among the most fatal injuries met with in the war. Particularly was this the case on the Western front, where during the long period of trench warfare the majority of such cases were shell wounds. Fracture of the femur, associated with a simple through-and-through small-bore bullet wound, may differ but little in treatment, prognosis and end result from a simple fracture in civil practice. A badly lacerated and mud-begrimed wound of the upper thigh with widespread comminution of the femur, however, is a type of injury in which pre-war methods of treatment, signally and hopelessly failed. This failure affected not one but all the phases of treatment. The methods of first-aid, operation, splinting, nursing and after-care all stood in need of radical change. It is not intended to imply that the surgical principles guiding pre-war practice were at fault. It was in matters of detail as to how to make practical the application of those principles that advance was essential. Thus the necessity of keeping a compound fracture at rest during transport and of avoiding disturbance during the process of dressing the wound had been recognized ; but surgery at the outbreak of war had not formulated methods of doing either.

Gradually but surely the various difficulties were overcome, and the end of the war saw a revolution in the treatment of fractured femurs. The chances in 1918 as compared with those in 1914 of survival with a useful limb of a man with a gunshot wound of the thigh with fracture of the femur constitute a striking tribute to the success of military surgery. In a subject, however, which has lent itself to specialization there is a natural tendency to seize upon certain aspects of the treatment, and place undue stress upon them as responsible for the improved results that became obvious in the later stages of the war. Actually no type of wound benefited more than did the fractured femur from the advance that was made in the general treatment of war wounds. The man with a fractured femur was the subject, almost more than any other, of shock, gas gangrene and secondary hæmorrhage.

All advances in the treatment of these conditions would in consequence, benefit him especially. While describing the special appliances, inventions and methods of operative treatment and after-care which developed as the result of the experiences of the war, it should be made clear that the efficient early cleansing operation was the basis of all successful treatment of the fractured femur, just as the improvement in the methods of combating and preventing shock at the advanced units enabled patients to be brought to the clearing stations in a condition which rendered such a formidable operation a possible proceeding. Everything, therefore, that has been written elsewhere as to the treatment of shock, the successful evacuation and transport of patients, the routine treatment of lacerated wounds and the methods of disinfection when sepsis has supervened, applies with especial force to the treatment of fractures of the femur.

Treatment before Arrival at the Casualty Clearing Station.—At the beginning of the war the routine splint for a fractured femur was the Liston's long splint. The inadequacy of this to meet the necessities of the case as a permanent appliance will be dealt with later in describing treatment at the base. Not only there, however, but as an appliance for first-aid treatment and early transport its shortcomings became obvious. The splint was generally used as a method of lateral fixation; it was fixed to the trunk of the patient and to the injured limb with bandages. Occasionally extension was also applied by the old-time method of fixing the foot to the lower extremity of the splint and attaching a perineal band to its upper end. In civil practice, however, where a Liston's splint had been the usual appliance for fracture of the femur, surgeons had been in the habit of employing extension by means of weight and pulley fixed to the limb by adhesive strapping. So much was this the case that the Liston's splints employed in hospital were often made without the holes at the top for the fixation of the perineal band or the ratchet end below for the fixation of the foot. Surgeons, indeed, had largely ceased to look upon the splint itself as a means of obtaining extension. Even where the original idea was maintained of using the splint for extension as well as for lateral fixation, it cannot be said that any very successful results were obtained in providing rest to the broken thigh during transport. The jolting and movement inseparable from prolonged transport over bad roads led to constant movement of the fragments, spasm of muscles, pain and continued hæmorrhage, so that the serious condition of shock in

which the wounded man reached the casualty clearing station was a constantly marked feature in the early part of the war.

The success that was being attained by the use of the Thomas' knee splint at the base and casualty clearing stations led to attempts being made to utilize this appliance as a means of fixation in the forward area. The difficulty was at once experienced that to apply an efficient extension satisfactorily by means of strapping occupied more time and necessitated more care and attention than could be given when large numbers of wounded were passing through the limited space available at regimental aid posts and advanced dressing stations. Moreover, it entailed considerable disturbance, and consequently the infliction of much pain to the unanæsthetized patient. Attempts were made to surmount this difficulty by placing a clove hitch of bandage round the ankle and fixing this to the lower bar of the splint. After some experience it was found that, in patients sent down in this way, either the ankle extension had become loose and inefficient, or else that the circulation had become seriously endangered, the foot swollen and the ankle cut by the bandage. It was then suggested by Captain Kenneth Walker that the bandage might be applied over the boot, which would protect the ankle and foot from injurious pressure. The fear that the retention of a wet and muddy boot on the foot of the damaged limb during transport might predispose to gangrene or trench foot fortunately proved to be unfounded. From the general adoption of this method of applying extension dates the universal employment in France of the Thomas' knee splint as a first-aid appliance for fractures of the femur and allied injuries. Considerable numbers of cases put up in this way arrived at the casualty clearing stations in 1916 and so favourable was their condition and so much less trying their journey when compared with those of patients coming down with other methods of support, that demonstrations in the necessary technique were given at field ambulances and to the officers of many divisions. Further experience of the method showed that by applying the extension and fixing the slings before cutting away the clothing and dealing with the wound it was possible to save the patient much pain, and reduce to a minimum the shock caused by preparing the patient for transport. When he was so prepared a further apparatus of the greatest importance was next utilized, namely, the "stretcher suspension bar." This had been perfected in the First Army early in 1916, and consisted of a stout metal bar supported by uprights

and clipped on to the stretcher so that the lowest part of the Thomas' splint could be suspended from it.

As a result of the wide adoption of the Thomas' splint before the heavy fighting in the early spring of 1917 at Vimy, Arras, and Bullecourt on the fronts of the First, Third and Fifth Armies, cases of fractured femur arrived at the casualty clearing stations in a far better condition than had previously been known. In the summer of the same year many demonstrations were given before the battles in Flanders to the medical officers of the divisions taking part in those actions. Many modifications and improvements had developed, and towards the latter part of 1917 and in the beginning of 1918 the institution of army schools, where divisional medical and ambulance personnel came for training, enabled these improvements to be co-ordinated and standardized. Team-work was essential for the rapid and efficient application of the splint, and the teaching of the "Thomas' splint drill" rendered this team work possible in spite of inevitable changes of personnel.

Consideration was also directed to the question of the stage in the line of evacuation at which the splint should be applied. The answer was "as far forward as practicable." During quiet times in the line the Thomas' splint was readily and efficiently applied in the trenches and at the regimental aid post. When pressure of numbers or battle conditions rendered this impossible the advanced dressing station was able to fulfil this duty, and the usual arrangements were that such cases should be sent from advanced dressing stations to casualty clearing stations direct. The supply of splints and stretcher bars was arranged by allotting a certain number to each field ambulance which kept the regimental aid posts supplied. Each ambulance car bringing down a case with a Thomas' splint obtained a fresh outfit from the casualty clearing station for return to the field ambulance. A reserve supply was maintained by each ambulance car carrying a spare Thomas' outfit. It was striking to note, even in the difficult days of March 1918, the efficient splinting of large numbers of the fractured femurs which reached the casualty clearing stations. The method of first-aid application of the Thomas' knee splint, as practised at the end of the war, is best described in the Thomas' splint drill which was devised by Captain E. M. Cowell, and taught in the School of Instruction for the Medical Services of the First Army. The full text is as follows (Fig. 1).

- I. Warming (*Réchauffment*).
- II. Extension.
- III. Clove-Hitch over Boot.
- IV. Splint.
- V. Fixation of Leg.
- VI. Dressing Wound of Thigh.
- VII. Gooch Splints and Triangular Bandages.
- VIII. Stirrup and Figure-of-8.
- IX. Spanish Windlass.
- X. Pad in Ring.
- XI. Suspension Bar.
- XII. Hot Water Bottles and Blankets.

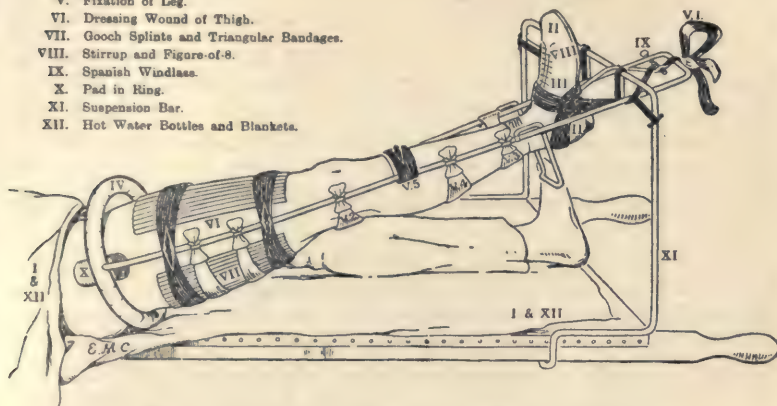


Fig. 1.—Front line application of Thomas' splint.

"Drill for Front Line Application of Thomas' Splint."

The Thomas' Outfit consists of :—

- Stretcher on trestles.
- Blankets, three. Primus stove.
- Thomas' splint (largest size).
- Reversible stirrup (Sinclair's).
- Suspension bar.
- Flannel bandages (6 yards), three.
- Triangular bandages, four.
- Dressings.
- Safety pins.
- Gooch splinting (10 in. by 6 in. and 8 in. by 6 in.).

Personnel required :—

Operator. No. 1 Assistant. No. 2 Assistant (if available).

When not in use the splint is kept hung up. The five slings of flannel bandages are rolled round the inner bar of the splint, the leather is kept soft by saddle soap, and the iron bars are smeared with vaseline.

Indications of Front Line Application.

1. For all fractures of the thigh bone, except where there is an extensive wound in the upper part of thigh or buttock, which would interfere with the fitting of the ring.
2. In severe fractures about the knee-joint or upper part of the tibia.
3. In certain cases of extensive wounds of fleshy part of thigh.

Detail of Thomas' Splint Drill.

I.—*Warming (Réchauffment)*. On the word "One."—The stretcher, placed on trestles, with a Primus stove beneath, is prepared as follows: The first blanket is folded lengthwise into three, two folds lie on the stretcher, one hangs over the side. The second blanket is arranged in the same way, one fold hanging over the other side of the stretcher.

The patient is now placed on the prepared stretcher and lies on four folds of blanket; the two folds hanging down form a hot air chamber. The third blanket is placed across the patient's chest, while the splint is being applied.

II.—*Extension.* On the word "Two."—No. 1 assistant stands at the foot of the stretcher facing the patient and opposite the injured limb. Grasping the heel of the boot with his right hand and the toe with his left, keeping the arms straight, he exerts a steady pull, thereby producing the necessary extension. No. 2 assistant supports the injured part above and below the fracture.

III.—*Clove-hitch.* On the word "Three."—To form the clove-hitch the operator takes a length of 9 ft. of flannel bandage. Holding it in the left hand by its mid-point, he grasps the centre of the left half with his right hand, palm to the right, and makes a loop which is carried up and passed behind the left hand, thus forming a clove-hitch with a diameter of 10 in.

This is applied over the boot, with the short end on the outer side; the long end is carried under the instep, up and through the loop round the ankle. The two extension bands thus produced are ready to be attached to the splint later on.

IV.—*Splint.* On the word "Four."—The operator threads on the splint, No. 1 assistant removing and re-applying upper and lower hands alternately to allow the ring to be passed over the foot. The splint should be pushed up under the buttock as far as possible, care being taken to keep the notched transverse bar horizontal. No. 2 assistant, as before, steadies the thigh.

V.—*Fixation of Leg.* On the word "Five."—1. The extension bands of the clove-hitch are tied round the notched bar at the end of the splint as follows: The outer band is passed over and under the bar, round the notch, drawn taut, and held over to the opposite side. The inner band is passed under and over the bar, then also round the notch where it crosses the first band and prevents its slipping. The two are finally tied off by a half bow.

2. The middle flannel sling is tied behind the knee, which is held partly bent by No. 2 assistant.

3 and 4. The slings behind ankle and calf are tied, so that the leg rests in a shallow trough, with its centre on a level with the long bars of the splint.

5. To prevent the leg rising off the splint a narrow fold bandage is placed across the leg, just below the knee; the ends are carried down between the leg and splint, brought up outside the bars and tied off in front of leg. The lower limb is now firmly fixed in a position of extension and it may be moved freely without causing pain to the patient or damage to the injured part.

VI.—*Dressing Wound of Thigh.* On the word "Six."—The wound is exposed by cutting away the over-lying portion of trousers on the front or back of the thigh, and the dressings are then applied.

VII.—*Gooch Splints and Bandages.* On the word "Seven."—The Gooch splints are now applied. The short piece is placed behind, and secured by tying the remaining two slings. The long piece is placed on the front of the thigh, care being taken to avoid pressure on the knee-cap. The whole is now retained in position by two narrow fold bandages, carried round the thigh outside the bars of the splint.

VIII.—*Stirrups and Figure-of-Eight.* On the word "Eight."—The stirrup is "sprung" on to the splint above the ankle, its foot towards the stretcher. A bandage is then applied to form an additional sling, and by a figure-of-eight turn prevents lateral movement of the foot.

IX.—*Spanish Windlass.* On the word "Nine."—The extension bands are tightened, and a small piece of wood or a nail is introduced to increase the tension by twisting up as required.

X.—*Pad in Ring.* On the word "Ten."—A pad is placed inside the ring on the outer side of the thigh to act as a wedge and prevent undue movement.

XI.—*Suspension Bar.* On the word "Eleven."—The suspension bar is fitted to the stretcher with the "grip" away from the rackets. The splint is swung up three fingers breadth from the horizontal part of the suspension bar. To damp down the side movements, lateral tapes are tied to the uprights. For the journey in the motor ambulance car an additional band may be passed from the splint round one handle of the stretcher.

XII.—*Hot Water Bottles and Blankets.* On the word "Twelve."—Hot bottles are applied. The third blanket is folded into two lengthwise, and laid over the patient. The hanging folds of the first and second blankets are brought up over this so that the patient is evacuated with four folds of blanket on top as well as underneath."

A second suspension bar across the middle of the stretcher, to which the ring of the Thomas' splint was suspended, made the retention of the ring against the ischial tuberosity much more certain, but whilst the second bar was in routine use for transferring patients from casualty clearing stations to the base, difficulties in the transport of additional equipment prevented its general use in the forward area.

Reports reached the casualty clearing stations from the base that a few cases of sloughing of the skin of the dorsum of the foot had occurred from the pressure of the extension clove-hitch. It is believed that these were due to the retention of the first-aid appliance for far longer periods than was proper or intended. To guard against this it became usual to cut the boot laces and to loosen the clove-hitch as soon as the man reached the casualty clearing station if no further operation was anticipated.

Treatment of Fractured Femur at the Casualty Clearing Station.

On arrival at the casualty clearing station an early decision had to be made as to the necessity for operation. In fractures caused by through-and-through bullet wounds with small apertures of entry and exit unaccompanied by signs of infection or evidence of serious hæmorrhage operation was unnecessary. The wounds were carefully cleaned and dressed with sterilized gauze and the limb put up in a Thomas' splint in a manner similar to that adopted after operation, and the cases were transferred to the base with the least possible delay. In a large proportion of such patients the subsequent progress of the case was similar to that of a simple fracture. If infection ensued operation was needed, and it was a great advantage, therefore, to get patients to the base early so that in the event of an operation being required, treatment and splinting on permanent lines could be arranged from the start.

In all cases other than such simple through-and-through bullet wounds, operation as soon as circumstances permitted was the routine, but a certain number of men were found to be in such a condition of shock as to necessitate their being sent to the resuscitation ward for preliminary treatment. In such cases the limb was not disturbed, the first-aid Thomas' splint being left in position, and the patients were sent to the theatre

when their condition had so far improved as to warrant it. Among these cases, however, were always found a few where the limb was hopelessly smashed and nearly severed, and in these a rapid amputation under gas and oxygen anæsthesia, as a preliminary to resuscitation treatment, aided rather than retarded their recovery from shock. It is difficult to make an examination of a fractured femur without considerable disturbance of the patient and the consequent risk of increasing shock and restarting hæmorrhage. For this reason it was frequently the practice to anæsthetize the patient on the operating table and not to remove the splint in which he was transported or to disturb the site of fracture until he was under the anæsthetic. On the other hand, there is no question that information as to the integrity of the main nerves, obtainable by testing movement and sensation, is of great importance in deciding as to the necessity for amputation. Moreover X-ray plates, or at the least a screen report from the radiologist, with special reference to the number and position of foreign bodies, is of great assistance to the surgeon in the performance of the cleansing operation. The general condition of the patient and the pressure of work on the X-ray department had, therefore, to be considered when deciding as to whether the patient was to undergo X-ray examination.

When the wounds were exposed the first point on which the surgeon had to make up his mind was whether the limb could be saved or whether immediate amputation was necessary. In making a decision the points to be considered were the amount of destruction of bone and soft parts, the condition of the main vessels and nerves, the presence of sepsis, or the likelihood of avoiding it by satisfactory excision of damaged tissue, and finally, the functional usefulness of the limb which would remain as the result of the success of conservative treatment.

If amputation was unnecessary the surgeon proceeded with the careful and complete routine cleansing operation. The soft parts were dealt with on the general lines laid down elsewhere ; all lacerated, soiled or devitalized tissues were freely excised, with the distinct reservation that the utmost care had to be directed towards the preservation of skin. It was essential to take away missiles and fragments of clothing. Access to the site of fracture was obtained by enlarging the apertures of entrance, and exit if such existed. It was very rarely necessary or justifiable to make a fresh incision for the purposes of the operation.

In dealing with the injured bone special judgment was required and the practice of surgeons varied. There could be no doubt that fragments of bone detached from the periosteum and driven into the surrounding soft parts by the force of the impact of the missile should be removed. Such fragments might be found lying in the aperture of exit and were for the most part distributed in the muscles between the site of fracture and that aperture. The excision of the wound always included the removal of such fragments. If left they necrosed and effectually prevented the healing of the wound. Any small fragments, detached from the periosteum yet remaining in alignment between the fractured ends of the bone, were also taken away. On the other hand, large fragments of the bone maintaining their periosteal attachment and in alignment between the fractured ends were retained in position. It was sometimes necessary to remove one such fragment to enable the surgeon to obtain access to the interior of the shaft, where foreign bodies, fragments of clothing or small splintered fragments of compact tissue might be lying. Where such a removal was decided upon it had to be a careful and deliberate proceeding. The periosteum was carefully raised from the fragment before removal and its integrity so far as possible preserved. To tear out such fragments roughly with sequester forceps or lion forceps is bad surgery. By such means valuable periosteum is sacrificed and strips of periosteum may be violently torn from the shaft above or below the fracture. Bare bony surfaces and the exposed marrow were thoroughly curetted and mopped over with spirit.

Between these two types of fractures remained a class in which the continuity of the bone was maintained only by fragments which had lost altogether their periosteal attachment. When large fragments in this condition were present between the fractured ends it was the general practice to leave them *in situ*, disinfecting them as far as possible by the above procedure. Where, however, portions of the femur had been completely carried away by the missile and small detached fragments only were left lying in the gap, little was to be gained by their retention, and the surgeon had to rely for eventual union on regeneration from such periosteum as might remain. It was found better to attempt to maintain the direct length of the limb even at the expense of a gap; satisfactory provision was thus made for drainage and local treatment of the wound.

Fear of non-union and of pseudo-arthritis and flail limb often deterred surgeons from the practice of removing completely

all fragments of bone not in direct continuity with the shaft. It is certain that large numbers of such cases of non-union were met with in fractures of the upper extremity. In the case of the femur, non-union was reported from England to be of rare occurrence. Conclusions were drawn from this that, while in the upper extremity it was important to preserve fragments, in the lower extremity there was little fear of non-union and loose fragments might safely be taken away. This deduction, however, appears to have been based on a fallacy; for the mere accessibility of the fragments of the humerus and the ease with which they were removed led the less experienced surgeons to deal very drastically with bone fragments in the upper arm, while the same lack of experience placed difficulties in the way of obtaining adequate exposure in the case of fractures of the femur. Moreover, in the upper extremity it was commoner to see a considerable length of shaft blown away by the projectile than in the case of the lower extremity.

A large group of French surgeons, however, practised what is termed "immediate esquillectomy," Influenced by the classical work of Ollier, the Lyons school of surgeons practised the subperiosteal removal of every fragment which had lost its continuity with the shaft. Leriche, in his work *Traitement des fractures*, claims that this can be done without fear of non-union. If this contention be true there can be no doubt that such removal renders the preliminary cleansing operation far more efficient and by so much improves the chances of the wound running an aseptic course. Further, it is undoubted that such a measure would obviate many of the most disastrous sequelæ in the shape of osteomyelitis, infection of the callus and prolonged suppuration due to the presence of sequestra. A study of Leriche's work, however, makes it clear that subperiosteal removal of fragments in his mind means something far different from that practised by those who have not followed his teaching. The careful, thorough and methodical elevation of the periosteum, together with the bone-forming layer on its deep surface, by means of the *rugine tranchant d'Ollier* with the preservation of every fragment of membrane present, is an essential part of the treatment. The general methods of dealing with fragments previously described is that which obtained among British surgeons at the end of the war, and while total esquillectomy had not given favourable results in their hands, it is at least doubtful whether the delicate technique insisted on by Leriche was often attained.

The wound of the soft parts and the bone having been dealt with, a decision had to be made as to whether the wound should be closed or whether it should be left temporarily open. In the circumstances of war on the Western front the patient with a fractured femur had to be transported to the base at the earliest opportunity, and consequently, it was seldom advisable to attempt primary closure. The wounded man was for practical purposes out of reach of adequate surgical treatment for 24 to 36 hours after leaving the casualty clearing station. Immediate closure therefore involved risks which had no sufficient compensating advantages and the wound was usually left open and packed lightly with gauze. Salt pack treatment and B.I.P. had their day, and during 1917 considerable numbers of cases were sent to the base with Carrel's tubes in position, arrangements being made for the instillation of Dakin's fluid on the ambulance trains. The difficulties, however, of ensuring intelligent continuity of treatment during the time of waiting for the train, on the train and during the early hours at the base were never overcome, and the use of Carrel's method of treatment during transport was almost given up by the end of the war. The final method in most general use was, as has been said, to pack the wound lightly with gauze, which might be wrung out of some antiseptic, flavine being widely employed for this purpose, and to leave it to the surgeon at the general hospital to close the wound by "delayed primary suture" if he thought it advisable.

Splinting for Transport to the Base.—The Thomas' knee splint was almost the only splint used for the purpose of sending a case of fracture to the base. Certain difficulties existed in putting up femurs for transport. Until the end of 1917, cases of fractured femurs at the base were not segregated as a routine. At Boulogne, it is true, a special femur hospital had been in existence since the early part of the war, but most of the cases of fractured femur were distributed to many base hospitals indiscriminately, and on this account, while the general principles of treatment varied but little, in matters of detail wide differences existed. It is unquestionable that a stereotyped method of applying extension and the Thomas' splint at the casualty clearing station—stereotyped, that is to say, according to the views of those who were to receive the cases at the base—possessed great advantages, and the first step towards this end was the establishment of special femur centres at each base. It then became possible for extensions and splints to be applied in such a manner that the minimum

of disturbance and readjustment was necessary on their arrival at the base. It not infrequently happened in the earlier years of the war that it was a chance whether a particular form of fixation employed by a surgeon at a casualty clearing station was that in vogue at the base hospital to which the patient was sent.

The general principles governing the putting up of the fractures for transport were as follows. An extension, either by glue or strapping, was applied to the leg. If the situation of the wounds permitted, this extension was often carried above the knee. The Thomas' splint having been placed in position, the leg and thigh were supported by interrupted slings of flannel or unbleached calico fixed to the side bars by safety pins or clips. The thigh was often with advantage supported by slips made of perforated zinc, which were hooked over the side bars. Retaining bandages were placed under the bars of the splint and over the front of the leg just below the knee to prevent the jolting of transport lifting the limb from the supporting slings. A foot-piece steadied the foot at a right angle. The foot of the splint was then slung to a suspension bar fixed to the stretcher, and a second suspension bar over the pelvis of the patient supported the ring of the Thomas' splint. Without this second bar it was found very difficult to keep the ring engaged on the ischial tuberosity. A firm pad between the great trochanter and the outer bar of the splint aided in maintaining the ring in position.

Treatment at the Base.—In gunshot fractures of the femur the general policy governing the treatment and disposal of cases was influenced by enemy action to a greater extent than in any other class of injuries. The treatment adopted at the base depended to a very large extent on the necessity of evacuating these cases early or the possibility of retaining them for long periods in France. In 1914 and the early part of 1915 it was the policy to transfer them to the United Kingdom unless their general condition was so grave as absolutely to prevent their evacuation. Necessary as this was on account of the conditions then prevailing, there is no doubt that the journey was bad for the patients.

During 1915 and the later years of the war there was a large and steady increase in the number of beds available, and more and more cases of gunshot fracture of the lower extremity—particularly those of fracture of the femur—were retained in France. This policy was further developed very considerably when the action of the enemy in sinking hospital ships made

it increasingly dangerous to transport cases of serious injury by sea, and numbers of new hospitals were established so that as many cases as possible might be retained in France.

A development in the opposite direction, that is, the evacuation from France of all the more serious cases, was necessitated in 1918 by the concentrated air attacks of the enemy on hospital areas at Etaples and Boulogne.

The evolution of the lines of treatment adopted in these injuries may be considered under two headings, namely, the general surgical treatment of the wound and the treatment of the fracture by mechanical means. The former has been dealt with elsewhere.

In the earlier part of the war the treatment of the fracture by mechanical means followed the practice usually adopted in British civil hospitals in peace time, namely the application of Liston's long splint with weight and pulley extension. This splint was in general use for fractures about the middle of the shaft, while for fractures of the upper or lower third, Hodgen's splint or a double inclined plane was used.

There were notable exceptions to the general use of Liston's long splint, and in certain schools other methods were taught. At Guy's Hospital, for example, Hodgen's splint was used more frequently than at other hospitals, probably because it was at Guy's that Hodgen's splint was first used in this country, and the advantages of the splint were regularly taught at that medical school. In Liverpool, where Thomas' methods were taught by Jones, it was a routine practice to treat fractures of the femur on one or other of Thomas' splints. In most fractures of the femur Thomas' knee splint was employed with fixed extension, but in fractures of the upper third with abduction of the upper fragment, a modification of a double Thomas' hip splint was employed. In this "abduction frame," as it was called, one limb of the splint is abducted and a prolongation of the limb bars and the attachment of a perineal band allow of extension being applied.

At the beginning of the war, surgeons in France used Liston's long splint and various modifications with weight and pulley extension. For purposes of transport to England what became known as the "Boulogne box" was used. This was practically a double Liston's splint with a floor to it, very much like Phelps' box. Liston's splint, however, was soon found to be an impossible apparatus for cases with large wounds of the soft parts to which access had to be obtained. It was also a very difficult apparatus in which to nurse patients

and very unsuitable for their transport, besides being inefficient mechanically.

As the war progressed Thomas' knee splints came more and more into general use. Jones urged the adoption of this splint in December 1914, and the intrinsic merits of the apparatus were soon appreciated by the surgeons who gave it a trial. As he pointed out, there is no support comparable with Thomas' knee splint for any fracture of the middle and lower thirds of the thigh, or for fractures of the knee or upper end of the tibia. It allows of easy access to the wound without disturbing the fragments and it permits of adequate and constant extension while correct alignment is secured. In addition, the patient can be transported any distance and in any conveyance with the minimum of discomfort. Its application requires little special knowledge as its construction is so simple.

The abduction frame, however, which Jones also advocated was very seldom used, as it was not found to be a suitable apparatus in which to nurse patients who were seriously ill with septic infection and with severe extensive wounds in the region of the hip-joint.

An exhibition of fracture apparatus, arranged by officers of the R.A.M.C., to illustrate the methods which had so far been found most useful in the war for the treatment of fractures, was held in London on 8th October, 1915, at the Royal Society of Medicine. The dominant feature of this exhibition was the skeleton frame, known as Thomas' knee splint, which with various modifications was used by practically all the officers who exhibited apparatus. In the later years of the war, Thomas' knee splint or some modification of it, was practically the only appliance which was used for the treatment of gunshot fractures of the lower extremity. Most surgeons found that the splint required some modification in order to get perfectly satisfactory re-establishment of the line of the bone and the greatest degree of comfort for the patient. In the main, these modifications consisted of flexion of the knee joint, variations in the methods of applying extension and the adoption of various methods of suspension.

Some surgeons adhered to the original method of using Thomas' knee splint with fixed extension. But to obviate the upward thrust of the upper ring of the splint against the ischial tuberosity most surgeons adopted a method of suspension which practically incorporated the advantages of Hodgen's system with those of Thomas' splint. The adoption of Hodgen's method of suspension and of extension of the whole splint

apparatus adds considerably to the comfort of the patient, and it may be said that with few exceptions this line of treatment became general in base hospitals in France in the later years of the war. It is interesting to note that this splint was designed by Hodgen during the American Civil War for the treatment of soldiers suffering from gunshot fracture of the femur. He made his splints from war material, which he found available in army stores.

The great advantage of Thomas' splint over Hodgen's is that it can be used without suspension being employed and that when suspension is being used and is discontinued, the tightening of the extension strips permits of the patient being moved and transported freely. On the other hand, Hodgen's splint must be suspended, and removal of the suspension may be said to remove the splint as well.

When administrative changes very greatly increased the number of hospital beds on the lines of communication a great stimulus was given to improvement in methods of treatment. Surgeons were able to retain cases under their care until they were well on the way to recovery. Not only was their interest thereby increased, but they were better able to realize and appreciate the difficulties of the various stages of treatment and the necessity of adopting methods which were suitable for use throughout the course of the case.

The result of this was reflected in improved statistics, which not only showed a marked diminution in the mortality of these cases and in the percentage of amputations, but also a great improvement in anatomical and functional results. At the same time the retention in France of such a large number of cases revealed the necessity for still further administrative changes. It is not every surgeon who has the necessary gifts, aptitude and inclination for the treatment of these cases, and it is not every nurse who is especially suited to look after them. There was found to be great variation in results and a comparison of these led to the best "teams" and methods being identified.

At the end of 1917 Sir Anthony Bowlby therefore advised that these cases should be concentrated in one hospital in each base. Carefully selected surgeons and nurses were chosen for duty in these hospitals and instructions were issued that these special staffs were not to be moved without orders from the Director of Medical Services on the Lines of Communication and after reference to the consulting surgeons. This concentration of cases in special hospitals led to still further improvement

in the results. It meant, however, that the surgical and nursing staffs had to be augmented. In one hospital, for example, there were at one time over three hundred patients with fracture of the femur.

The improvements which followed the adoption of this policy must not be attributed entirely, however, to the concentration of cases in special hospitals under the care of expert surgeons, but also to the general improvement in the treatment of wounds, to the increased facilities at casualty clearing stations enabling a larger number of these cases to be operated on, and to the adoption of Thomas' knee splint with suspension bars as a standard appliance from the time of injury until convalescence.

When this organization had been brought to its highest state of efficiency, the bombing of hospital bases in France in 1918 necessitated the evacuation of cases from these areas and resulted in the transference of some of the "teams" to England, where special hospitals for cases of fractured femur were then established.

With regard to the general results of these injuries, the following extract from a memorandum by Sir Anthony Bowlby gives some idea of the mortality, amputation rate and the amount of shortening and the contrast in results between the earlier and later periods of the war.

"The mortality at the front in the early days of the war cannot be directly compared with the mortality at the front in 1918, because the conditions were totally different.

"In 1914-1915, whenever there was heavy fighting practically all patients were at once sent to the base hospitals by ambulance trains, and very large numbers of patients merely passed through the casualty clearing stations on their way to the trains. Yet even then it was found that not less than 16 per cent. of 1,000 consecutive cases died at the front, and it was estimated that the total mortality in France was at least 40 per cent., exclusive of those who subsequently died in England, so that the death-rate was altogether not less than 40-50 per cent.

"These figures are, however, rather misleading, for all cases of fractured femur are included in them, and amongst these not less than 20 or 30 per cent. had either such serious local complications as injury to the main vessels, extensive comminution into a joint, or widespread laceration and destruction of large masses of muscle, whilst many other patients had multiple wounds involving other limbs or the viscera of the thorax or abdomen. It is not possible to differentiate between all these conditions, and it must be understood that the figures used in this communication include all patients in whom the femur was fractured, whatever complications there might have been.

"The total mortality in the year 1918 may be estimated from the following figures. It has been found impossible to ascertain accurately the exact number of cases and their results in all the casualty clearing stations, because of the difficulties encountered in the retreat of March and April, but sufficient records have been obtained to enable satisfactory conclusions to be drawn.

(I) *At the Front.*

"Of 3,141 cases admitted into various casualty clearing stations, 550 died, *i.e.*, 17·5 per cent.

"Of these cases approximately 21 per cent. were treated by amputation.

"The mortality of the amputated cases was about 33 per cent.

"These are included in the total of 550 deaths recorded above.

"It was estimated that in between 20 and 30 per cent. of the total number of 3,141, there were multiple wounds or such other serious complications as have been alluded to above. The mortality was very much higher in this class than in the remaining 70 per cent.

(II) *At the Base Hospitals.*

"During the year 1918 there were treated in general hospitals at the bases in France 5,025 patients; of these, 547 died, *i.e.*, 10·8 per cent.

"Of these 5,025 cases, 513 were treated by amputation, *i.e.*, 10·2 per cent. The mortality of the amputated cases was about 33 per cent. All these are included in the figure of 547 given above.

"Enquiry in England shows that the mortality in the special hospitals there has been very low, and has generally been about 1 or 2 per cent. This is due to the fact that

(1) The majority of all the cases were kept in France till union had occurred and the wounds had healed.

(2) Even in times of stress the worst cases were retained in the special hospitals in France.

"Amputations in England have for the same reason been few.

"From a consideration of the above figures it may be concluded that during the year 1918 the total mortality of all cases of fracture of the femur (*a*) at the front, (*b*) at base hospitals in France, and (*c*) in England, amounts to approximately 30 per cent.

"It must, however, again be pointed out that a very large proportion of the deaths occurred in men who had other serious injuries, and there is no doubt that in not a few of these, death was not due to the fracture of the femur, but to wounds of the viscera or to the shock caused by multiple injuries. My own impression is that the mortality of uncomplicated fractures of the femur due to 'gunshot' wounds and treated throughout by the most modern methods is not more than 15 per cent., and this conclusion has been arrived at after a long experience of these cases both at the front and in the base hospitals, and after an examination of many statistics.

Amputations.

"A very large number of the deaths followed amputation, and about 30 per cent. of all the patients with fracture of the femur lost the limb. It will also be noted that in one-third of all the amputations the operation failed to save life.

"At the front the most common cause for amputation was that the extent or severity of the injury rendered it impossible to save the limb. In other cases laceration of the main vessels was the cause. In many cases the operation was performed for gas gangrene.

"Many lives were saved by the employment of transfusion and by the use of gas and oxygen as an anæsthetic.

"At the base hospitals the presence of gas gangrene was almost as often the cause of amputation as at the front, but in a good many cases the development of intractable sepsis called for the removal of the limb. It must, however, be remembered that in March and April 1918, some hundreds of cases had to be sent to the base for operation which would ordinarily have been performed in the casualty clearing stations.

"The following figures of one general hospital may be taken as examples. Out of 71 amputations, gas gangrene caused 24, acute sepsis 29, dry gangrene 3, secondary hæmorrhage 9, and osteomyelitis, etc., 6.

"The final results obtained in the limbs that were saved show a very great improvement on those of the early part of the war.

"*Shortening*.—The present methods of treatment guarantee that unless there has been very extensive loss of bone no shortening need occur. It has been shown that even when one or two inches of the femur may have been destroyed, the gap can be filled by new bone, and that consequently there is no objection to maintaining the fractured ends in full extension.

"It had formerly been the practice of some surgeons to allow the separated fragments to come together so as to promote union, but it is certain that this should not in the future be a regular practice.

"Practical experience has also shown that it is more difficult to obtain a full-length limb in cases of simple fractures, such as occur commonly in civil practice, for the uninjured muscles offer far greater resistance than those in a limb wounded by shell or bullets, and more extension is consequently required. The amount of shortening following gunshot fractures is shown by the following figures to have steadily decreased in each year of the war.

"For these we are indebted to Major Stout, N.Z.M.C., and they include every case of fractured femur in the New Zealand Corps.

New Zealand Figures.

					Cases.		Average Shortening.
1916	..	..	..	..	54	..	1.345 in.
1917	..	..	..	..	116	..	0.957 in.
1918	..	..	..	..	90	..	0.25 in.

Two Special British General Hospitals in France, 1918.

					Cases.		Average Shortening.
(a)	343	..	..	..	..	..	0.2 in.
(b)	60	..	..	..	..	..	0.2 in.

"Of these last 60, 36 had no shortening.

A Special Hospital in England, 1918.

"Lieutenant-Colonel M. G. Pearson, S.A.M.C., has supplied the following figures :—

Cases.			No Shortening.			Average Shortening of the remaining 29 cases.
68	..	..	39	..	..	0.5 in.

"Other hospitals show similar results, and it will be seen that the majority of the patients recovered without any shortening, and in only about 5 per cent. of all cases was there more than one inch of shortening. Thus, of the 90 New Zealand cases in 1918, only two had more than an inch of shortening, and both of these patients had lost a good deal of bone.

"The records of the various special hospitals necessarily vary somewhat, but the figures quoted are sufficient to prove that the previous difficulties in obtaining limbs of good length after gunshot fractures of the femur have been completely overcome, and that equally good results should be generally obtained."

According to the special problems which they present in treatment, fractures of the femur may be considered in three groups : (1) fractures of the upper third ; (2) fractures of the middle third ; (3) fractures of the lower third.

Fractures of the Upper Third.—Gunshot fractures of the neck of the femur involve the hip-joint and are frequently associated with necrosis of the head of the bone. Fragments of bone and often the head have to be removed, and posterior drainage established through the buttock. The mechanical treatment consists in applying traction in an abducted position.



Fig. 2.—Upper third fracture, showing abduction of upper fragment—the usual type.

In fractures above the small trochanter, the upper fragment is abducted with a tendency to outward rotation as the result of the action of the glutei. The limb must be put into an abducted position to bring the lower fragment into line with the upper, and must be flexed at the hip to relax the ilio-psoas muscle. If there is outward rotation of the upper fragment, the foot must be rotated outwards.

In fractures below the small trochanter, the upper fragment, besides being abducted and slightly rotated outwards, is tilted

forward to a certain extent (Fig. 2); the limb must be abducted and flexed to bring the lower fragment into line with the upper.

While this is the usual displacement in fractures below the small trochanter, it not infrequently happens that the line of fracture runs obliquely downwards and inwards, and the



Fig. 3.—Upper third fracture with adduction of upper fragment—the exceptional type.

upper fragment is then drawn inwards by the contraction of the adductor brevis (Fig. 3). The limb must then be put into a position of adduction instead of abduction in order to re-establish the proper alignment of the bony fragments.

Fractures of the Middle Third.—While fractures in this section show a great variety both in their character and in the deformity which results, the usual displacement is for both fragments to sag backwards, while there is a tendency for the

lower fragment to be drawn inwards. Traction in the line of the thigh will cure any tendency to lateral bowing, while tightening of the slings in the middle of the thigh will counteract the tendency for the fractured ends to sag.

Fractures of the Lower Third.—The lower fragment is tilted backwards by the action of the gastrocnemius. The upper end of the lower fragment is tilted obliquely outwards and also rotated outwards by the contraction of the adductor magnus. These special deformities are also associated with some overlapping.

These displacements are corrected by flexion of the knee-joint and powerful traction of the thigh. The difficulty of controlling the lower fragment in these cases by extension applied below the knee has long been recognized, and in this situation perhaps more than in any others the value of extension applied directly to the bone has been demonstrated.



Fig. 4.—Thomas' splint with knee-flexion piece added.

Methods of Treatment.—The following extract from Sir Anthony Bowlby's memorandum gives an accurate summary of the general lines of treatment which were followed in these cases in the last years of the war.

"No single method was in universal practice as far as details are concerned, but the general principle of the application of a metal skeleton splint and extension was universally adopted.

"(1) The employment of the Thomas' splint and the stretcher suspension bar at the front, and as far forward as possible, enabled men to be transported with infinitely less shock and pain, and was instrumental in saving many lives.

"(2) At the base hospitals the splints were either the Thomas or the Hodgen. An additional splint, fitted so as to allow of flexion of the knee at varying angles, was in very general use. It was the invention of Major Watkin-Williams, and proved of great service (Fig. 4).

"(3) *Extension.* 'Fixed' extension was generally given up in favour of weight extension. In some hospitals the weight was attached to an extension apparatus fixed to the thigh and leg and was suspended at the foot of the bed. In other hospitals the foot was fixed and the weight of the body was used by raising the foot of the bed to a sufficient extent to reduce all shortening. Either glue or strapping was at first employed to fix the extension apparatus to the limb, but in an increasing number of cases steel callipers were fixed to the femur just above the condyles and direct traction was made by these upon the bone itself.

"This calliper extension was particularly useful in correcting the tendency to backward displacement in fractures just above the condyles and it proved to be a completely satisfactory method of dealing with this difficulty.

" The calliper extension was also most useful when employed in conjunction with the Watkin-Williams splint for flexion of the knee, and was used in all cases of fracture of any part of the femur by many surgeons.

" (4) With a fracture treated by these methods it was easy to move daily all the chief joints, and the knee, hip and ankle could be massaged, flexed and extended without pain and without disturbing the fracture.

" The treatment of all cases was very greatly facilitated by a specially constructed bedstead and mattress, both of which were arranged in sections so as to permit of easy access to any wound, and were constructed from plans made by Lieutenant-Colonel M. G. Pearson, S.A.M.C., and adopted by the War Office for general use in England.

Fixation of Fragments by Operation.

" With the improvements in splinting and extension the need for fixation operations became extremely rare. They were not employed in as much as one-half per cent., and then were almost limited to the encirclement of fragments by wire. Plates and screws were practically never employed.

The Use of X-rays.

" Frequent examinations by X-rays proved to be one of the most important essentials in the treatment of fracture of the femur, and it is also essential that the X-ray apparatus shall be taken to the bedside of the patient. Without such an employment of radiography it is quite impossible to appreciate the exact position of the fragments, and unless this is ascertained replacement is necessarily impossible. A movable X-ray apparatus was part of the equipment of every special hospital for fractures of the femur in France, and much of the success in the restoration of useful limbs is due to its employment as a routine method for observing the progress of every case.

" It is also necessary to take frequent measurements of the length of the limbs.

Treatment of Necrosed Bone.

" All cases of gunshot fracture of the femur require early operation at the front, and at the time of operation all the shattered fragments of bone which are scattered in the muscles and subcutaneous tissues must be removed. Large splinters and partially separated fragments should not be removed, as they frequently do not die and are of great service in the process of union. Many fragments that do necrose can be easily removed from the wound without a formal operation, but if the dead bone is more deeply placed such an operation should not be unduly delayed.

" Operations of this kind appeared to be needed in between 20 and 30 per cent. of the cases, and were generally performed between the eighth and fourteenth weeks after injury.

" The early and complete 'subperiosteal esquillectomy' advocated by French surgeons was practised in an increasing number of cases during the year 1918. It appeared on the one hand to shorten the period of suppuration and of the healing of the wound, but in the opinion of some surgeons it caused delay in the union of the fracture. It still has its advocates and its opponents.

Treatment of the Wounds.

" The results have very greatly improved in proportion as the practice of 'delayed primary suture' has increased.

" In one hospital in France (No. 8 General) suture was successful in 161 cases out of 211 submitted to operation, and it is probable that not less than one-third of all such cases can be successfully closed within ten days.

" The closure of the wound very greatly diminishes risks of all kinds of complications and results in a much more rapid union of the fracture, a more speedy convalescence, and an earlier return of powers of walking.

" When suture is not possible cases have been treated either by Carrel's method or else by free drainage."

The lines of treatment adopted at the base may now be considered in more detail. This subject has been dealt with very fully by various authors in medical journals and much of the following information has been freely extracted from the article by Captain A. B. Le Mesurier in "A Manual of War Surgery," edited by Barling and Morrison, and from "Fractured Femurs," by Pearson and Drummond.

If operation has not been carried out at the front, then it will be required in every fracture case with a lacerated wound as soon as possible after the patient's admission to a base hospital. But in these injuries, while the length of time before recovery of function depends mainly on the character and progress of the wounds, yet this progress and the final usefulness of the limb depend largely on keeping the fragments in good anatomical position. The earlier a good anatomical position is obtained the better. Correction becomes increasingly difficult as time passes. Measurements of the limb must be taken and X-ray examinations made. The fragments being restored to their proper alignment, it is necessary to retain them in that position until consolidation has taken place in a splint that allows of ready access to the wound and of sufficient extension.

The results obtained depend more on constant care and attention to detail than on adopting any one line of treatment, and there is probably no class of case that so repays in final results the attention expended on it. On the whole, gunshot fractures of the femur are probably the most tedious cases with which the surgeon has to deal.

There are certain details of splinting, attention to which will well repay the surgeon.

Slings.—The material used for slinging the limb in the splint should be double and fastened to the outer side-bar with strong wide paper clips. The slings should be of some soft material adaptable to the contour of the limb but without too much "give." Old linen sheeting is probably the best. Care should be taken that the weight of the limb is evenly distributed and that there is no wrinkling of the slings. There must be no undue pressure over sensitive parts, such as the tendo Achillis or the peroneal nerve in the region of the neck of the fibula. Failure to avoid pressure on this latter spot both in applying extension strips and in the placing of the uppermost leg sling may easily result in peroneal paralysis and foot drop.

The most important sling and the one that should be applied first is that supporting the lower fragment which generally

tends to fall backwards. This sling should be applied as high on the thigh as the wound permits.

Methods of applying Extension.—For glue extensions the best glues are Heusner's spirit glue and Sinclair's glue. Heusner's formula is as follows :—

Methylated spirit	..	..	50 c.cm.
Benzine	..	..	25 c.cm.
Resin (commercial)	..	..	50 grm.
Venice turpentine	..	..	5 grm.

Unless carefully applied and renewed every two or three weeks, the extension is liable to give completely without much warning.

Sinclair's glue is excellent, especially where there is a limited area of skin from which to take extension. The following is the formula and the method of application of the glue as recommended by him.

Very good glue	..	..	..	50 parts.
Water	..	..	..	50 parts.
Glycerine	..	..	..	4 or 6 parts.
Menthol	..	..	..	1 part.

The skin must be thoroughly cleansed, but not necessarily shaved. The glue is applied warm with a broad brush, moving from below upwards, and allowed to get a little "tacky." Strips of flannel bandage or of ordinary roll-gauze are then evenly applied to either side and fixed in position by a firm bandage. A strong pull may be taken within ten minutes of applying.

If adhesive plaster is used, the skin must be shaved as well as thoroughly cleansed. The strips of plaster should be wide, 4 in. is a good width, and should be held in place by a firm bandage only. Encircling strips of plaster tend to become tight if the extension slips a little and may cause pressure sores. An important detail is that the bandage should always be firm and should be re-applied frequently as the leg shrinks.

In a very large number of cases it was impossible to carry strips of strapping or glue extension higher than the knee-joint, owing to the presence of large septic wounds. This meant that extension was carried out from below the knee-joint and resulted in a curious condition of plastic arthritis of the knee in which, although there was considerable lateral rocking of the tibial tuberosities against the condyles of the femur, the joint could not be bent. Even if the strips could be carried above

the knee-joint, prolonged immobilization of that joint led to so much stiffness that it was difficult to overcome it.

From the beginning of the war, surgeons were anxious to obtain freedom of the leg and mobility of the knee-joint and to avoid pulling on the knee-joint itself. In order to do this it was essential to apply extension above the knee and in most cases some form of instrumental extension was necessary. There was, as a rule, so much sepsis in the limb that surgeons were averse to driving rods through the bone to apply extension, but the introduction of "Besley's callipers" which did not go through the bone, provided a means of traction which was mechanically almost ideal and surgically free from most of the disadvantages hitherto urged against instrumental devices. In their original form they tended to penetrate the bone unduly and various modifications were introduced to limit or prevent this penetration. The one which was particularly useful was that devised by Pearson, whose modification consisted of a check-bar between the handles adjustable by a screw. This check-bar prevents the inward thrust of the points, for after applying the callipers the screw can be adjusted so as to prevent or limit penetration of the bone (Fig. 5).

To apply the callipers the skin of the thigh is pulled slightly upward, and a small incision made down to the bone, on the inner side, just above the adductor tubercle, and on the outer side at a corresponding level above the broadest part of the condyle and just in front of the ilio-tibial band. The points are inserted and held in place until extension is applied. The skin wounds are dressed with flavine 1-500. Coating the points of the callipers with hard paraffin is said to make them less irritating to the tissues. The callipers should not be applied through tissues that are acutely inflamed, but may be applied near or even through a wound that is quiet and granulating. With ordinary care there is no risk of damaging the knee-joint in applying the callipers.

The advantages of direct extension applied to the bone are that it allows a greater pull with less discomfort to the patient, and that the pull is not taken through the ligaments of the knee-joint. The method was generally adopted by some surgeons, while others reserved it for the cases in which blistering was caused by adhesive extensions or when the site of the fracture or site and character of wounds rendered the available area of skin too limited to allow of adhesive extension being applied.



(a)



(b)

Fig. 5.—(a) Non penetrating callipers applied (Pearson's modification of Besley's). Note attachment of cord; the white area on the bone is covered by synovial membrane of the knee-joints. (b) Lateral view of same.

Methods of supporting the Foot.—The support of the foot is a matter of some importance, and various appliances have been devised in order to secure the requisite support without preventing movement of the ankle-joint.



Fig. 6.—Suspension of the foot by a bandage glued on to the sole. Note the bare dorsum of foot and tendo Achillis.

One of the simplest methods is that by which the foot is suspended from the top of a skeleton iron foot-piece by means of a bandage previously glued to the sole. This provides a very satisfactory method of keeping the foot at right angles to the leg, and at the same time of avoiding pressure on the tendo Achillis, where pressure sores may be serious (Fig. 6). It leaves the dorsum of the foot bare, and movement of the toes and ankle is unimpeded.

When it is desired to maintain the limb in any particular degree of rotation the foot-piece devised by Sinclair will be

found useful. Strips of flannel, on which are threaded two metal triangles, are first glued to the sole and lateral aspects of the foot. The Thomas' splint is then applied, a padded wooden foot-piece is placed in position, its transverse metal bar riding



Fig. 7.—Side view showing abduction extension cord and pulleys attached to projecting limbs of cross-bars.

on the Thomas' splint. The triangles are threaded with tapes, which are passed round the serrated foot-piece and tied. The foot is now under complete control. By slackening the clamp fixing the foot-piece to the bar, the foot can be rotated inwards or outwards and raised or lowered.

Special Apparatus.—Other apparatus which were found useful, particularly for the treatment of fractures of the upper third of the femur, were the Bryan bed, the Sinclair net frame,



Fig. 8.—Wounds exposed for dressing without disturbance of the patient.

Jones' abduction frame, the application of a Thomas' knee splint to each limb, and a form of Thomas' knee splint with a double ring devised by Captain Dennis Crile of the Harvard

Unit. Most of these appliances have been devised with the object of abducting both limbs. It is maintained by Pearson that it is unnecessary to abduct the sound limb in cases of fracture of the upper third, and that no attempt is made by



Fig. 9.

the patient either voluntarily or involuntarily to defeat the object aimed at by abducting the fractured limb.

The Bryan bed consists of a sectional bed, made by slinging strips of strong Bavarian flannel between two Balkan frames, joined by transverse bars at head and foot. Abduction is

secured by slinging the injured limb from an adjustable overhead bar. The bed was designed with the idea of keeping patients immobilized with the limb abducted, and at the same time allowing access to wounds at the posterior part of the hip-



Fig. 10.

joint (Figs. 7 and 8). It was superseded at a later date by the Sinclair net frame* designed with the same object in view, by the body sling used at No. 2 Australian General Hospital (Figs. 9, 10 and 11), and by the sectional bed introduced by Colonel Pearson.†

* See p. 376.

† See p. 373.

The most successful and most generally used methods of treatment were those adopted by Pearson and Drummond and by Sinclair.



Fig. 11.

These two methods may be taken as a general model on which the treatment of these cases was based, though they were of course modified to a certain extent in the hands of various surgeons.

The objects which Pearson and Drummond had in mind were mainly that traction should be made in the line which

produces most accurate alignment of the fragments and should be applied as directly as possible to the bone; that mobility of the adjacent joints should be procured; that a splint should be used which does not require to be changed during after-treatment; that the method used must make dressings easy for patient and surgeon; that it should be as painless as possible, capable of giving good results both anatomically and functionally, and be free from new dangers of its own; that radiography must be freely available and applicable without moving the patient; and that, from the point of view of health, convenience and of fire risks in hut hospitals, the bed, appliances

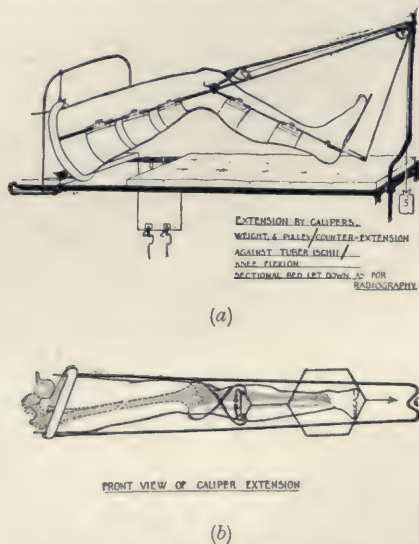


Fig. 12.—Adaptation of Thomas' splint to permit of knee-flexion.
(a) from side; (b) from front.

and patient should form one "self-contained unit" capable of being carried or wheeled out *en bloc*, and not attached in any way to the structure of the building.

Put very briefly, the method advocated consists in "weight and pulley" traction in the line of the thigh through a special form of ice-tong callipers which grip but do not penetrate the lower end of the femur. The limb remains throughout on the large-ringed Thomas' splint which was applied immediately after the injury, but grafted on to it is a hinged knee-flexion splint, on which the leg, from the knee downwards, lies free, flexed, supported yet movable, and in practice moved every

day from the beginning. The patient is nursed on a high bed of sectional type. The general plan of the method, as used before union occurs, is shown in Fig. 12.

Pearson and Drummond describe their method as follows:—

"Assuming that the patient is already on a straight or nearly straight Thomas' splint, with some sort of adhesive extension applied below the knee and tied to the lower end of the splint, the first step is to fix the lower end of the splint firmly and immovably to an extension post at the foot of the bed, and high enough to give considerable slope to the limb. The hinged knee-flexion splint (Fig. 4) and narrow foot-piece are then fixed by means of a thumb-screw to the Thomas' splint at the level of the knee, so that the weight of the leg below the knee can be transferred to this when desired and at any degree of flexion with the thigh

"The application of the traction callipers is a matter of a few moments, and can be done under local anæsthesia. On the whole we prefer to use nitrous oxide gas because it enables us, after applying the callipers, to strip off the adhesive strapping, or whatever may have been previously used, rapidly and without hurting the patient.

"If operative treatment, supplementary to the primary operation, is necessary, the callipers may be inserted while the patient is in the theatre, but it is more convenient to do it in his own bed

"One hand grasping the two blades holds them in position firmly pressed against the bone, while an assistant rapidly ties the two handle-ends together with a piece of stout blind cord, attaching the other end of the cord to the iron hexagon on the other end of which the weight pulls. The weight is a 5 lb. bag of sand in a recent case, and up to 10 lb. or 15 lb. in an old case. The weight being allowed to act, the grasp of the hand may be relaxed. The callipers will continue to grip firmly as long as the weight is undisturbed. Nurses and others must be made to understand very clearly that lifting the weight-bag for a single moment releases the grip of the callipers and may dislodge them.

"While the patient is still under gas the old glue or strapping extension is stripped off, leaving the leg bare from knee to toes. The leg is supported finally on the knee-flexion splint, which is lowered to the desired angle, and fixed by means of the light chain or cord shown in Fig. 6.

"The foot is suspended from the top of the foot-piece by means of a bandage previously glued to the sole only

"The efficiency of the method of extension here described depends upon the pressure of the ring of the splint against the tuberosity of the ischium. That alone prevents the weight from gradually pulling the patient down the bed into the splint. The relative position of the tuberosity and the ring must therefore be frequently scrutinized by the surgeon; as long as the ring is suspended there should be no trouble; the tuberosity should not slip past the ring, nor should the skin become sore from pressure

"It will be noted that as a rule we do not tilt the bed or depend at all upon the body-weight as a means of counter-extension; that is to say, the method is nearer the Thomas' than the Hodgen principle With weight and pulley extension and a level bed, the pull is absolutely constant, cannot be varied by the patient, and is a known quantity.

"There are only two occasions on which there is necessity for tilting the bed. If for any reason the skin touching the ring of the Thomas splint should become tender to pressure, tilting the foot of the bed up a few inches will cause the patient to slide slightly towards the head of the bed; the splint cannot slide with him because its lower end is tied to the extension post, and so the pressure between the buttock and splint is relieved and in that case the splint becomes a 'Hodgen' rather than a 'Thomas.' But this reason for tilting the bed should rarely exist, since soreness, and still more, blistering or breakage, of the skin in this region nearly always betoken wrong placing of the ring or want of attention to skin and ring."

Fracture Bed.—Pearson and Drummond describe the fracture bed as follows :—

"To avoid the need for moving the patient for dressing, etc., we worked out in 1916 and 1917 the details of the bed shown in Fig. 13, a form of fracture bed easily improvised where the later standard pattern is not at hand. Many stages of evolution occurred in No. 1 South African General Hospital in France, where every attempt had to be made to utilize available materials and such bedsteads as were obtainable quickly and in large numbers.

"Owing to the number of early cases sent to England in 1918, the army medical authorities there adopted as a standard pattern an improved form which contains all the essentials of the South African bed, with the addition of a supply of tubular overhead gear which makes it suitable for almost all forms of fracture suspension and extension.

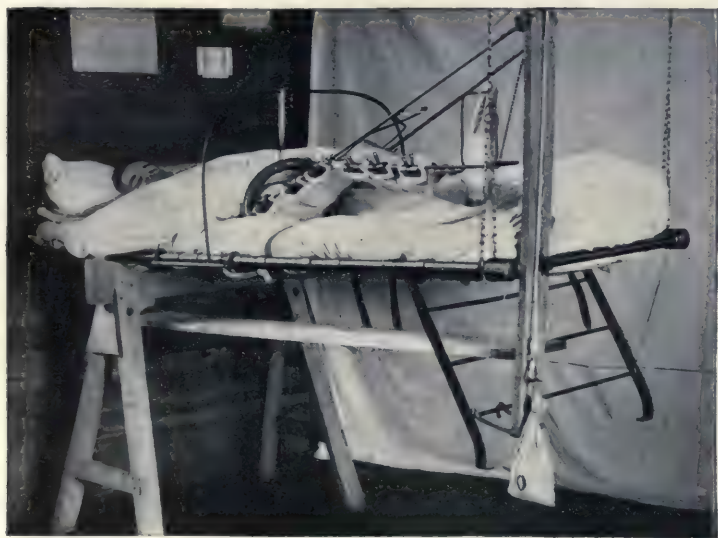


Fig. 13.—Improved form of fracture bed, made by stripping the spring mattress from an ordinary camp bedstead and replacing by canvas slings and straps. Lower end of bed suspended by chains from the roof to lessen vibration and give increased height.

"The bed is intended primarily for cases of fracture of the femur, but it is also useful for wounds of the arm, shoulder, back or pelvis, where turning the patient is difficult. It is an extension of the 'sectional mattress' idea, with this addition, that not only the mattress, but the whole of that part of the bed which underlies the wound can be removed altogether, giving unimpeded access either for dressing the wound, radiography or for ordinary nursing purposes, so that it is unnecessary to move the patient at all.

"It consists of a tubular frame bedstead, with the spring mattress replaced by tight canvas slings, 11 in. wide, fastened by straps and buckles to one side-bar of the bedstead and by metal hooks or a 'quick-release' contrivance on the other (Fig. 14).

"The mattresses lie upon the tight slings in three or more sections. For a femur case, one square 'biscuit mattress' is under the patient's head and body, another under the lower part of the legs and a small piece of mattress of the same breadth as the canvas slings lies immediately under the wound and is the one that is removed with its corresponding canvas for dressing purposes.

"As a matter of convenience for nursing and radiography the bed stands 36 in. high, a good deal higher than ordinary hospital beds. A removable arch of round iron resting on the side bars of the bed or the tubular beam shown in Fig. 15 affords means for suspending the Thomas' splint, or the pelvis of the patient if it is necessary to expose a large part of the back or buttock at one time. For a femur case, it is never necessary to lower more than one canvas section at a time.

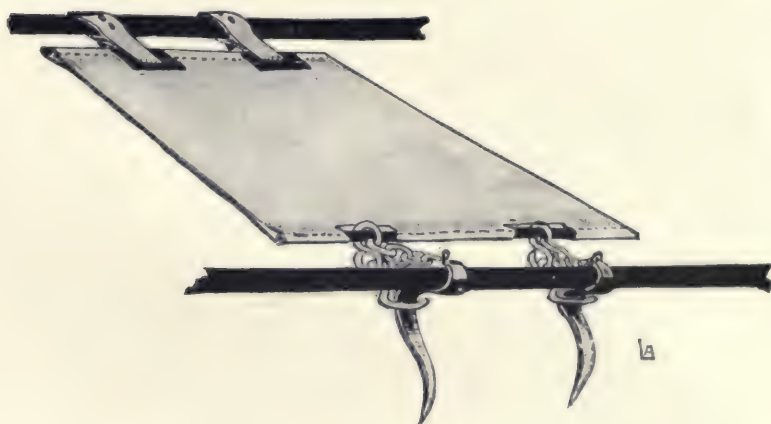


Fig. 14.—A canvas sling with straps at one end and "quick release" at the other.

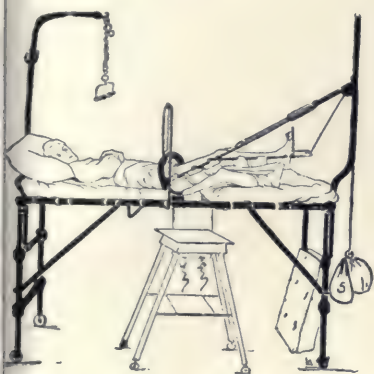
"The upper bed legs are furnished with wooden wheels, the lower are telescopic so that the bed can be up-tilted without blocks if body-weight extension is desired. At the head end is the derrick by which the patient can raise himself. It cannot rotate because its lower end is hexagonal. It can, however, be put into any one of six different positions and can, for instance, project sideways to suspend a damaged arm. At the foot of the bed, near each corner, is a similar hexagonal socket into which a spare derrick can be inserted to suspend a leg, or a steel tubular extension post with pulley attachments can be inserted. For ordinary fractures of the femur, or tibia and fibula, one such extension post is sufficient, and the lower end of the Thomas' splint is tied against it at any slope that is desired. In the case of the upper fourth fractures, where wide abduction of the leg is required two extension posts are put in and a long tube clamped horizontally across them projecting far beyond the side of the bed; to this projecting end the splint is fixed. In a similar way a bar may be clamped on to the upright derrick at the head of the bed to suspend or extend an injured arm. The overhead suspension is of light bicycle tubing connected where necessary by clamps of the Maddox type."



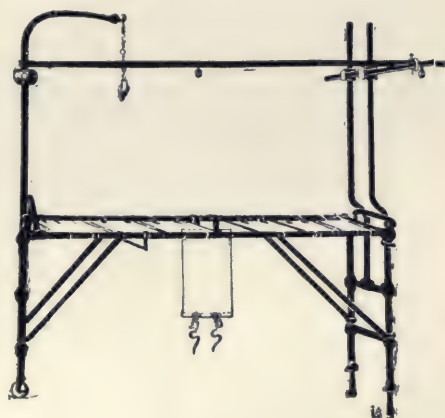
(a)



(b)



(c)



(d)



(e)

Fig. 15.—Fracture bed. (a) As arranged for fractured femur, middle or lower third. (b) Arranged for upper third fracture, with abduction. (c) Section of bed let down for dressing purposes. (d) With Balkan beam arrangement and lower end of bed uptilted by telescopic legs. (e) Arranged for fractured arm as well as fractured leg.

Sinclair's Method.—In contrast to the method adopted by Pearson and Drummond, that introduced by Major Sinclair met with very wide acceptance. In Sinclair's method Thomas' splint was used essentially on the Hodgen principle and Sinclair's methods of suspension and his many ingenious modifications of the method of applying Thomas' splint gave much comfort to the patient. At first Sinclair used Thomas' splint with fixed extension and his suspension apparatus was only designed with the idea of giving greater comfort to the patient, allowing him greater liberty of movement and very much facilitating all nursing and dressing procedures. At a later date he bent the splint opposite the knee-joint, fixed the lower end of the splint to an upright at the foot of the bed, and by raising the foot of the bed, used the patient's body-weight as a method of applying extension. He generally applied extension by strips of gauze attached to the limb with glue. At a later date he used hinged knee-flexion splints and callipers of a special pattern which could only penetrate the bone to a limited extent. With the use of the flexion leg-pieces and callipers for gripping the bone, Sinclair continued to rely on raising the foot of the bed and thus using the patient's weight for establishing the requisite extension. His methods were followed by many surgeons with great success and there can be no question that the incorporation of the Hodgen principle into the use of the Thomas' splint does away with any disadvantages of that splint. The constant pressure of the upper ring against the tuber ischii with the possibility of the ring being displaced and the whole system of extension being upset is sometimes a serious disadvantage and a source of great discomfort. As has been said previously, however, the results obtained and the comfort of the patient depend more on the constant attention of the surgeon than on specially designed apparatus.

One of the criticisms levelled against the methods adopted by Sinclair was that the upright at the foot of the bed was not incorporated with the bed itself, but was attached to the hut. There is no doubt that in case of fire or bombing this might prove a serious disadvantage, but it is one that is easily overcome, for the upright can quite easily be fixed to the bed, if so desired. Another disadvantage is that whenever the patient has to be moved, the foot of the bed lowered, and the splint detached from the upright standard, the extension strips must be tightened and the apparatus converted into one for fixed extension. This disadvantage also can be overcome by the upright being fixed to the bed, and the patient can then be carried on the bed into the open air.

For fractures of the neck of the femur and some fractures of the upper third of the shaft with large wounds in the buttocks, Sinclair designed a net frame which facilitated dressings and nursing duties (Fig. 16).



Fig. 16.—Sinclair net bed.

Fractures of the Tibia and Fibula.

The first-aid treatment of these injuries varied according to the position of the fracture. Where the fracture was in the upper part of the leg Thomas' splint employed as for the femur was by far the best appliance for transport. In fractures of the lower part of the leg, however, or about the ankle a wooden back splint with foot-piece was efficient, provided always that wide and strong side splints were applied in addition. Without these the heel almost invariably slipped out of the angle of the splint and fixation failed. The original back splint and the side splints were too narrow, but this fault was remedied later.

At the casualty clearing station the same general rules as laid down for fractured femur governed operative treatment. Injury of the main vessels was, however, a very frequent occurrence, and in many cases both the anterior and the posterior tibial vessels were divided by missiles passing

through the interosseous membrane. Where this had occurred the prognosis, as far as saving the limb was concerned, was unfavourable. Extensive laceration of muscles was usually present and gas gangrene was very liable to develop.

In most fractures of the leg both bones were involved, and were usually fractured at the same level. Occasionally with a compound fracture of the tibia a simple fracture of the fibula is present at some distance from the wound.

Fractures of the fibula alone were associated with no special deformity, and apart from immobilization of the limb, demanded no special attention.

If both bones are fractured, the factors that most commonly contribute to displacement of the fragments are the contraction of the muscles, which leads to shortening of the limb; the weight of the foot, which rotates the lower fragment to one or other side; and insufficient support of the calf, which results in sagging at the site of fracture.

In fractures of the lower third of the leg, contraction of the gastrocnemius and soleus muscles, together with the weight of the foot, often tilts the lower fragment so that its upper extremity is directed forwards. To relax the tendo Achillis, the limb should be fixed with the knee slightly flexed. Slight flexion at the knee-joint generally renders the patient more comfortable, and may be adopted with advantage in all fractures of the leg.

Non-union is a complication to be feared in fractures of the shaft of the tibia, and fragments of bone must be carefully preserved.

The apparatus which has proved by far the most valuable in the treatment of fractures of the leg is Thomas' knee splint. This splint is almost universally applicable. Provision is made for extension and counter-extension, and, since the apparatus is complete in itself, it allows both for the easy transportation of the patient and for continuous treatment in hospital. It is simple and readily applied and gives good access to the wound. In hospital the splint is suspended from a Balkan frame or other apparatus (Fig. 17). When the patient travels, the splint may be suspended from a bar attached to the stretcher. When the fracture is low down and there is little skin available for the application of extension, the foot-piece devised by Sinclair will be found useful.*

In multiple wounds, where extension cannot be obtained from the dorsal and lateral aspects of the foot, a few pounds

* See p. 316.

extension can be applied to the sole of the foot by means of a method designed by Sinclair. A plaster cast of the sole is made, and when dry is glued to the foot. In the plaster cast are incorporated tapes which serve to secure the wooden foot-piece detailed above. When greater extension is needed resort may be had to Finochietto's stirrup or, better still, Besley's callipers.



Fig. 17.—Balkan Frame.

Fractures of the Tarsus and Metatarsus.

The primary operative treatment of wounds of the ankle-joint, tarsus and metatarsus calls for little special description. Wounds of the soft parts and those of the bones are treated on the general lines laid down in dealing with fractures of the femur. It is advisable, however, to emphasize a point which is not always kept in mind. The foot as a weight-bearing appliance is a delicate mechanical contrivance. The integrity of its various joints is essential to the proper performance of its function. Extensive destruction of the bones of the tarsus

will, even when healing has taken place, leave a stiff " wooden " foot, too often a cause of pain and suffering to its possessor. Not infrequently risks were taken, valuable time and labour were expended, and great ingenuity was exercised in order to save a foot which was of so little eventual use to its owner that he implored amputation to get rid of it. Should amputation become necessary it is now a matter of almost general agreement that partial amputation of the foot should not be practised. Neither Lisfranc's amputation, Chopart's amputation nor sub-astragaloid amputation give any result superior to that given by Syme's amputation, and indeed they present many disadvantages. When the injury has not produced extensive destruction of the tarsal bones every effort must be made to retain any foot that may eventually be efficient as a weight bearer, but at the same time it must be remembered that sepsis spreads very easily amongst the tarsal joints and the cancellous bones of the foot, and no undue risk must be run to save a foot which may not be efficient. In making incisions it should be remembered that it is particularly important for the sole of the foot to be preserved intact if possible. The position of choice in which to treat fractures of the foot is one of slight inversion.

Many ingenious splints and apparatus were devised for the immobilization of an injured ankle. Jones' skeleton ankle splint was often used and many forms of foot suspension in the Thomas' knee splint. On the whole, some method of glue suspension of the fore part of the foot to a skeleton frame was the usual plan adopted.

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CHAPTER XII.

ORGANIZATION FOR ORTHOPÆDIC TREATMENT OF WAR INJURIES.

THE institution of special military orthopædic centres, the organization of massage services, and the fitting up and equipment of rooms and other details for remedial exercises, played an important part in the orthopædic treatment of injuries during the war and afterwards.

Military Orthopædic Centres.

Before dealing with the conditions which immediately preceded the formation of military orthopædic centres, it would be as well to review the position of orthopædic surgery in order to see how a branch of surgery, the name of which suggests a direct connection only with children, came to have such an important bearing on military surgery as to necessitate the formation of nearly a score of special hospitals under an Inspector of Military Orthopædics.

Orthopædic surgery began with the correction of deformities in children, so as to enable crooked children to be made straight and recover the use of disabled limbs and body. The treatment necessary for doing this does not consist simply in performing an operation to correct the wrong position, leaving nature to complete the cure, but involves a long course of re-education in the use of the injured limbs to restore their function. The same principles of treatment being found applicable to physical disabilities resulting from accidents in factories, in mines, and on the battlefield, this branch of surgery enlarged its borders and included the treatment of physical disabilities of adults as well as of children.

Although England held an important position in this branch of surgery, the University of Liverpool alone among the universities of the British Islands possessed a lectureship on Orthopædic Surgery. Among the great teaching hospitals in London orthopædic sections were few in number and consisted mainly of out-patient departments, the surgeon in charge dealing with the special cases under his care without corresponding accommodation for in-patients. Throughout the country there were a few surgeons doing orthopædic work without any official recognition by authorities of hospitals or of teaching schools that this branch of surgery was worthy of a surgeon's whole effort and industry.

In America the position was different, for there nearly every hospital had its special orthopædic section staffed by surgeons who were expected to devote themselves to this department of work. The position of orthopædic surgery was so well defined in America that for about half a century the American Orthopædic Association has flourished as a distinct scientific society, and their strength in surgeons trained in orthopædic ways of thought and methods of treatment has an important bearing on the subject under consideration. Methods of treatment in American clinics necessarily varied in different hands, but an examination of the root principles underlying their work shows that much of it was based on the work and teaching of Hugh Owen Thomas, the predecessor of Robert Jones in Liverpool and the founder of that school of orthopædic thought and practice which for the last twenty-five years has made the clinics of Liverpool the goal of pilgrimages of a long succession of surgeons from all parts of the world. The reason for this was that the teaching enunciated there maintained as a doctrine that orthopædic practice in surgery meant the restoration of function in disabled limbs by all means possible ; and of these means operation was only occasionally necessary as part of a larger scheme of re-education of voluntary function. Further, it was taught that the principles and methods employed for the treatment of children, disabled by disease of bone or joint or by infantile paralysis, could be made applicable to the treatment of adults suffering from similar disabilities whether caused by disease or by accident. The idea of treating disabilities due to injury by careful re-education of voluntary function in the disabled limb as well as by operation had already been established and the War Office recognized the importance of appointing an officer to organize this work on behalf of the wounded soldiers.

Conditions immediately preceding the formation of military orthopædic hospitals in the early months of 1916 must next be reviewed. The necessity for military orthopædic hospitals was only one of the special needs which the first eighteen months of the war had made apparent, and the formation of special hospitals or sections of hospitals for face injuries, head injuries, cardiac disorders and lung conditions following the use of poison gas, all began about the same time. The first reason for these new institutions was the magnitude of the war and the number of the wounded ; the second was that the advances made in wound treatment had made it possible to save many lives and limbs which would formerly have

been lost. In consequence of this the hospital accommodation in the United Kingdom was subjected to a severe strain, and it became necessary to discharge from the army men with stiff hands, with legs that were not fit to carry their weight, with muscles shrivelled from inflammation or paralysed because the nerve supplying them was divided. There were no institutions in existence with adequate accommodation or equipment to cope with the task of restoring these men. Men were being discharged from hospitals, not fit to fight, not fit to earn their living, and a source of national discontent. The time was therefore ripe for introducing new ideas and organizations into the scheme of military hospitals.

The work of correcting deformities and restoring function in disabled limbs is usually a slow process requiring definite treatment without interruption in its continuity. It was essential therefore that once a wounded man had started on a course of treatment he should remain in the hospital until it was completed. This entailed the establishment of special hospitals which should be immune from orders to "evacuate" patients in order to make room for new arrivals. Further, it was necessary that the surgeons selected for this work should not be moved but should remain and complete the work they had begun. An Inspector of Military Orthopædics was therefore appointed, and military orthopædic centres were established in quick succession to the number of seventeen, which, with auxiliary annexes, had accommodation for about 30,000 patients.

The decision having been made that military orthopædic hospitals should be created, the task of arranging their work fell to the Inspector of Military Orthopædics. The ideal he had in mind was that centres should be planted in every part of the country so that ultimately every discharged soldier requiring further treatment or repairs to any apparatus he might be wearing should be within reach of a special centre. This, however, could not be attained at once. Two difficulties had to be met, and the first was the shortage of surgeons with previous experience in orthopædics to set the hospitals going. As already stated, the practice of orthopædic surgery as a special branch had not been much encouraged by English hospitals and schools of medicine. The second difficulty arose from the fact the younger men who had given considerable attention to the subject were scattered with the armies and could not be taken from their work in the field, or only by degrees.

The first beginnings were made at Alderhey in Liverpool and at Shepherd's Bush in London, by taking over workhouse infirmaries and proceeding to make the necessary structural alterations. The aim of military orthopædic hospitals was primarily to stop the waste of man-power and usefulness due to wounded men being left too long without definite reconstructive and re-educative treatment of disabled limbs, and it immediately became apparent that, besides the actual physical treatment, mental treatment would be necessary. An atmosphere of expectancy and hope had to be created, and in this the curative workshops played a great part, though it was some months before they could be got into working order.

In brief outline the constitution and arrangement aimed at in these special surgical hospitals were as follows: first, surgeons with orthopædic experience, or those who had taken a special interest in the surgery of bones and joints, or injuries of nerves, had to be found to take charge of and direct the line of treatment and perform the necessary operations. Next, medical officers of suitable experience were required for the special departments. The departments which were absolutely essential were:—

(a) Massage department, which leads up to elementary movements of limbs and simple exercises.

(b) An electro-therapeutic department, in which examination of nerve injuries was undertaken to help in determining exactly what nerves were injured or divided, and electrical stimulation of paralysed muscles carried out to keep those muscles in proper condition while nerves that had been sutured were healing and regenerating, and also to help the patient to feel that his muscles were beginning to act. The electro-therapeutic departments were further equipped with apparatus for treatment by electric baths, sinusoidal current, high frequency, ionization methods of medication, Finsen and ultra-violet light.

(c) A psycho-therapeutic department for the treatment of so-called cases of "functional disability." The successful working of this department depended entirely on the personality of the director and assistants working in it. Each of them had to be allowed to take his or her own method of teaching a patient who from long disuse of muscles after an injury had forgotten how to make his own brain control the muscles in question. This department had to employ both electrical stimulation and massage as well as "suggestion."

(d) Gymnastic treatment for recovering cases, beginning with individual treatment of patients with local disabilities of limbs or back and ending up with general gymnastic treatment to make them fit to be returned to the army for further service or, if not physically fit for military service, to earn a living in a civil capacity.

(e) A radiographic department was, of course, an essential part of the equipment of every hospital.

(f) Balneological departments were also equipped with "whirlpool baths," paraffin baths, contrast baths and numerous other special appliances for assisting in making dense scars more pliable and stiff joints more mobile.

Curative workshops and employment at useful work in and about the hospital formed an essential part of the treatment of cases which had to be under treatment for many months. The first and most important function of employment was the maintenance of self-respect and discipline. Men who have no literary or other studies to occupy their brains are very prone to become inveterate idlers, and soon develop into discontented grumblers, for even entertainments pall when they are not a relief from labour. Regular hours of employment at useful work, the results of which could be seen and appreciated, encouraged a man to believe that he would again become a useful member of society. In the next place, the work chosen was, as far as possible, work which helped in the re-education of his wounded limbs, and the man was put to handling tools which he was accustomed to use. The idea of teaching a trade came last. In the workshops, as elsewhere, the psychological factor played a very important part. Among many the idea of self-help and self-education was very weak. The man who had started from nothing and worked himself into some employment in which he was his own master was, as a rule, a more easy patient to teach than the man who was only a journeyman workman, however skilled. It was interesting to note that men of the latter class often lacked perseverance. At first it seemed the natural thing to put them to handle the tools they knew, but the result was often despair; they could not handle the tools almost automatically, as they were accustomed to do in the past, and they had not the patience to teach themselves afresh. These men often came to the surgeon saying they could not manage their own trade and they wished to learn something else. When put to some entirely different work their initial clumsiness and difficulty did not hurt their feelings, for they had no past

dexterity in the new occupation. They therefore exercised more patience, and by learning a new form of work recovered dexterity and ultimately returned to their own trade.

The way in which the work was carried out may be illustrated by following the career of individual types of cases. Every case sent to a military orthopædic hospital was seen by one of the orthopædic surgeons in charge, who then became responsible for the direction of the whole treatment until the patient was discharged either to the army or to civil life.

Dealing first with wounded men, the history of the wound, sepsis, gas gangrene, previous operations, was first obtained. Then the man's present condition was investigated. Generally the case would come under one of the following groups, often under two or more :—

(1) Compound fractures of long bones.

(a) Still septic with sequestra.

(b) Wound healed but fracture un-united.

(c) Wound healed but fracture united in faulty position.

(2) Wounds of joints and fractures involving joints. This includes flail joints, the result of great loss of bone by injury or by wide excisions, and stiff or ankylosed joints.

(3) Injuries of muscle, including divided tendons and muscles impaired by being involved in masses of scar tissue.

(4) Injuries of peripheral nerves, producing paralysis or impairment of muscles and sensory disturbances.

(5) Disabilities due to faulty position, in which one group of muscles and ligaments had been allowed to get short and the opposing group long. These were very common in the earlier years of the war, but were almost eliminated in the case of patients wounded in 1917-18, for by that time the general principles of preventive treatment of disabilities had become the practice in all the war areas, and a supply of appropriate splints was more generally available.

(6) Functional and reflex disabilities. Men with these disabilities formed a large and often very difficult group of patients, too often accused of malingering. The purely functional case is exemplified by the man whose arm was kept for weeks or months in one position while some wound was slowly healing. During all this time certain muscles not directly injured were never used, the brain never received any sensations of movement from those muscles, and to all intents and purposes had forgotten their existence. The man could not get the proper parts of his brain to start working. Too often these cases had been accused of malingering and had

been psychologically mismanaged. Many cases could be cured in one lesson, others in a week of daily lessons repeated two or three times a day. The first essential was that the patient should have confidence in the surgeon. This was usually to be won almost at once if the surgeon was really interested in the disability—helping the patient to put his limb in different positions, and waiting till the brain had time to appreciate the sensations involved. Encouragement had generally the desired effect, but it required patience and unfailingly sympathetic handling. Cases to be distinguished with difficulty from these purely functional cases were those where the functional disability was reflex. A common type was to be found in injuries of the hand, when a careful examination might detect a small tender point on a twig of a sensory nerve somewhere in the scar. Any attempt to use the hand caused a twinge of pain, and the patient consequently kept his hand in a curled up position to protect the tender spot. Sometimes the fault might be in entanglement of a nerve in a scar in the arm. Operations to remove the tender nerve point were often indicated.

(7) Malingering. Genuine malingerers were comparatively rare in orthopædic hospitals.

Having determined on a line of treatment, the surgeon generally found it best to explain to the patient in simple words the plan he intended to follow, but allowance had to be made for the mental attitude of the patient when admitted to the hospital. Many patients had already lost heart, and were not prepared to believe at once that any new treatment was likely to benefit them, and they were specially unwilling to face any further operative treatment. With such patients it was best to temporize, and to arrange with the sister of the ward that they should come into contact with patients who were near the completion of their treatment for a similar injury. In the meantime X-ray photographs and electrical tests of the condition of injured muscles and nerves were made. After a week the surgeon could approach the patient again with the hope of finding him more ready to listen to suggestions for his future treatment. On the other hand, some patients were anxious for further treatment, and were in no way dismayed by being told of a prolonged course of treatment.

A good example of this type was a young flying officer who had received seven machine-gun bullets through his left forearm and hand, with the result that his limb was shrunk and useless from the elbow downwards. He had quite prepared himself to

hear that nothing could be done, and amputation had already been suggested to him by more than one surgeon. When he was told that a series of four or five operations at intervals of a few months to try to find and join the ends of his median and ulnar nerves, to straighten and repair the broken bones and finally to make a new wrist joint, might possibly restore a measure of usefulness to his hand, his reply was: "That means in about two years I may begin to get some use of the hand; that is the best news I have heard yet. Go ahead!"

This case illustrates what is meant by a programme of reconstructive surgical treatment. First seen at Shepherd's Bush Hospital more than a year after he was wounded, the patient still had two open sinuses leading down to small fragments of dead bone, and all muscles and soft parts of the forearm, except immediately below the elbow, were shrivelled and matted to the bones by dense scar tissues. The first step was to remove all pieces of dead bone and get the sinuses to heal. The next was assiduous massage, partly to soften the scar tissue and partly to see if massage would light up any latent foci of sepsis. The next operative stage was undertaken several weeks later, and consisted in a dissection of the scars to find out where the ends of the divided median and ulnar nerves were situated. Wide gaps were found in both nerves, that in the ulnar being too wide to permit the ends to be drawn together; the ends of several torn muscles were found and laced to torn tendons lower down, and the two ends of the median nerve were laced to each other. Another period of massage followed. During this stage recovery of function took place in some of the muscles which had been freed and repaired at the previous operation. At the next operation, as the result of recovery of some muscular movement, the deeper parts of the scars in the arm were found to be much less dense than at the previous operation, and it was possible further to stretch the median nerve and bring the ends almost into apposition. It was also possible to recognize one or two portions of tendons which were hidden in the deeper parts of the scar, and attach them to distant portions of tendon. After a further period of massage, another operation was performed to make a false joint at the wrist, and definitely suture the median nerve end to end. Now, three years after the commencement of treatment, this patient is beginning to play games, and is anxious to have a nerve graft operation done in the ulnar nerve, as he says, "as an experiment." This was not done earlier because the whole track in which the nerve graft would

have to lie consisted of scar tissue, and there was practically no prospect of the graft being successful.

The measure of success which has followed this prolonged course of treatment is mainly due to the indomitable perseverance of the patient in making the greatest possible use of every recovery in muscle movement, however slight.

Experience showed that reconstructive operations on bone, such as bone grafting for ununited fractures, or the division and re-setting of bones in cases of malunion of fracture, required careful preliminary treatment. The great risk was recrudescence of a sepsis which would cause death of the bone graft or caries of the divided ends of bones. In addition to suitable treatment by appropriate vaccines, the tissues were massaged for some weeks before operation, and operations were not performed till six months or more had elapsed since the last sign of sepsis had disappeared.

In cases of non-union of fractures, and in injuries involving joints, limbs often became distorted, and before any reconstructive operation could be performed it was necessary to correct the distortion gradually with splints or by repeated slight corrections, followed by fixation of the limb in plaster of Paris. Similarly, after nerves had been sutured, limbs had to be kept on splints in the position most favourable to recovery of the paralysed muscles, while the nutrition and wellbeing of the limb were maintained by gentle massage and electrical stimulation. The numbers of these cases in intermediate stages of treatment were so great that auxiliary hospitals were affiliated to the main orthopædic centres so that patients could be sent to them for a change of air, thus releasing beds for the accommodation of cases requiring a more active stage of treatment, the essential point being that these affiliated hospitals were under the control of the central or main hospital. There was therefore no breach of continuity in the plan of treatment. In the later years, after this group of hospitals had established a reputation for themselves, a formidable programme such as has been indicated in no way dismayed the patient, but on the contrary gave him a feeling that he had arrived at a place where his case would be dealt with thoroughly and on a definite plan.

In the beginning many difficulties had to be overcome. All the departments had to be created. Apparatus was required for the massage rooms and electric department. X-ray rooms and plaster rooms for treatment in plaster of Paris splints had to be planned and equipped. Splints suitable for the special work could at first only be obtained in Liverpool, but it was

soon obvious that the best plan was to start new workshops and make the apparatus and splints in them. The workshops at Shepherd's Bush did not get into full work till the winter of 1916-17, but then they began to turn out apparatus both for themselves and also for the sister institutions which were being established all over the country on similar lines, either as self-contained hospitals, or as sections of existing hospitals devoted to this special branch of surgery.

In this way, in addition to the original institutions at Alderhey and Shepherd's Bush, military orthopædic centres were equipped and established at Birmingham, Bristol, Leeds, Oxford, Whitchurch (near Cardiff), Newcastle-on-Tyne, Manchester and Reading. In Scotland similar institutions were formed at Edinburgh, Glasgow and Aberdeen, and in Ireland at Blackrock (Dublin) and at Belfast. Later, special hospitals were formed, one at Tooting for cases of nerve injury, and another at Edmonton with a very large department for fractures of the femur. These, however, only came into existence gradually as trained surgeons could be found or made available to staff them, and as equipment for them could be provided. From first to last the generous support of the Joint Committee of the British Red Cross Society and Order of St. John was of the greatest service in providing splints, workshops and special instruments.

The institution of military orthopædic hospitals as a separate group was not at first viewed with favour by all surgeons. This arose partly from a want of knowledge and appreciation of a larger scheme of reconstruction and re-education of limbs which the Inspector of Military Orthopædics had in view, and partly from lack of appreciation of the difficulty of equipping more than a limited number of institutions with all the special departments during a time of war. The need for concentration to economize time, expense and trained staff was very great.

In 1916 when these hospitals were first started, troops were being trained everywhere and hospitals, intended for wounded, which happened to be in the neighbourhood of training camps, were inundated with recruits who had broken down under training owing to defects in their feet or to chronic synovitis of knees. In consequence of this, the cases first admitted to Shepherd's Bush in April and May of 1916 included a large number of cases of hallux valgus, claw foot, flat foot and similar conditions, and a number of these patients were made fit for service by training, by operation or by manipulative treatment.

The other cases first received included a very large number of patients with gunshot injuries of bones and joints who had in most cases already been in other hospitals. Evacuated from a central to an auxiliary hospital to make room for a fresh convoy from overseas, they had been sent back to the central hospital because their wounds had "flared" and an operation was needed to evacuate pus and remove dead bone. Often, they could not be sent back to the surgeon who had treated them before, and so no continuity of treatment was secured. It is therefore no wonder that at this stage, malunion, delayed union, and non-union of fractures were common. At first it was difficult to persuade these patients to undergo further operations or to make them realize that they would not be moved to the care of still another surgeon till treatment was finished. Gradually, however, as the work went on, all that was needed was to leave new arrivals alone for a few days till they had talked to some of the other patients who had been successfully treated, and, as a rule, no further difficulty was met with.

By the time of the battle of the Somme in July 1916 arrangements had been made for sending a certain number of special cases, such as joint injuries and fractured femurs, direct to the military orthopædic hospitals, and as the benefits of early fixation in proper splints and of rest in a correct position became evident, the need for more special hospitals was appreciated.

The results which were thus being obtained were watched, not only in the United Kingdom, but also in America, and consequently the American Army Medical Department decided that they must have similar hospitals ready should they enter the war. The result was that within seven days of America's declaration of war Major Goldthwaite, the president of the American Orthopædic Association, sailed from America with twenty American orthopædic surgeons, who were sent to work under the Inspector of Military Orthopædics with two objects: first, to help to tide over the shortage of specially trained men till British surgeons could be spared from the armies abroad, and second, to get as much experience as possible in English military orthopædic hospitals before they went to the newly formed American army orthopædic centres. This accession of staff, soon reinforced by another contingent of twenty surgeons selected by Major Goldthwaite, made it possible to open up additional centres in the United Kingdom, and the first twenty American orthopædic surgeons were distributed

amongst the military orthopædic hospitals. Another effect of this increase of staff was that surgeons could be withdrawn from existing institutions to start other hospitals in different parts of the country, while to replace them the Inspector of Orthopædics selected surgeons in France who had previously had experience of similar work.

Courses of instruction were now begun, clinical demonstrations were given and lectures arranged. These were partly for the instruction of the newly arrived American officers, partly in order to give officers on leave from France an opportunity of seeing the work performed in the United Kingdom, and to help them to deal with cases in the first instance so as to leave no gap in the continuity of treatment. This interchange of ideas was also particularly useful to the surgeons in the orthopædic hospitals, for it produced a better comprehension of the initial difficulties which had to be overcome in France by the surgeons who first treated the patients. Soon, during the winter period of comparative inactivity, when surgeons could be more easily spared from the war areas, medical officers came in groups for courses of instruction, although it was not till the very end of the war that this could be done regularly.

Gradually and steadily, from 1916 onwards, the methods of splinting recent fractures and injured joints became systematized throughout the hospitals in the various war areas. Individual surgeons were encouraged to follow out their own methods and ideas and to consult with each other, and surgeons from different areas in France met at different orthopædic centres and compared their methods and saw the final results of treatment. Thus, by exchange of ideas and by comparison of methods and results, a spirit of mutual helpfulness was created, and whether a case of fractured femur came straight to England, or was kept in one of the special fracture hospitals in France, the principles and methods of treatment were similar and men were no longer subjected to entirely different methods of treatment as they passed from one hospital to another.

The military orthopædic hospitals continued under military control till near the end of 1919, and then some of them passed over to the Ministry of Pensions in order to continue their work. Captain McCrae Aitken, one of the four surgeons originally appointed to Shepherd's Bush orthopædic hospital and afterwards officer in charge there under the Ministry of Pensions, on re-examining his patients at the end of 1919, brought to light a significant fact. The cases wounded in

1918 formed only 10 per cent. of the whole, the remainder being 1917, 1916 and 1915 cases. All the latter were pensioners with maimed limbs who, in the earlier years, had originally been discharged from hospital to make room for others at a time when there were no orthopædic institutions to receive them. In the later stages of the war as the result of the close co-operation between surgeons working in France and in the United Kingdom, the completeness of recovery from wounds was most satisfactory. This success indicates the necessity of having, in the event of future wars, a sufficiently large nucleus of special hospitals and specially trained surgeons in the country so that the proper reconstructive and re-educational treatment can be carried out from the outset.

Reviewing the work of orthopædic centres during the war the fact that a large proportion of patients treated were recruits, suffering from deformities or disabilities which might have been cured had they received proper attention during childhood or adolescence, again emphasizes the need for these special hospitals in times of peace, not only to ensure that the unfit recruit will not in future hamper the work of the military hospital, but also as a means of improving the health of the nation as a whole.

Massage during the War.

On the 9th June 1920 a Royal Charter was granted to the Chartered Society of Massage and Medical Gymnastics, and though this event took place so long after the armistice, it will remain the link which connects the history of massage in this country with that of the war. That a charter would be granted some day was hoped in August 1914; that it would be granted within six years seemed impossible. But in those six years members of the massage profession made good, in the national emergency, their claim to recognition. They owe it to the opportunity provided by the war, but they were ready for the emergency when it came, and their reward in the granting of the charter is the permanent recognition which has been so well earned.

In 1894 a few women united with the common object of raising the standard of massage and of improving the professional position of women taking up this employment, for they felt that a valuable and honourable profession was endangered by untrained persons whose methods and aims were frequently undesirable. In 1900 the society was incorporated, and was thenceforth known as the Incorporated Society of Trained

Masseuses. In 1905 the Incorporated Society was asked by the Army Medical Service to examine hospital orderlies ; and this was done at Netley and subsequently at the Queen Alexandra Military Hospital, Millbank, twice yearly till stopped by the war. Thus for nine years previous to the war the Incorporated Society had held direct connection with the army.

Before the close of August 1914 Mr. and Mrs. Almeric Paget started the Almeric Paget Massage Corps, and thus originated a service which ultimately developed into the Military Massage Service. At first the corps consisted of fifty members, but this number was soon increased to a hundred. In November 1914 Mr. and Mrs. Paget opened an out-patient clinic in London at 55, Portland Place (later at 2, Cambridge Gate), for the treatment of wounded officers and men. This was inspected by the Director-General of the Army Medical Service in March 1915, and subsequently became the model for the massage and electrical departments in the convalescent hospitals and command dépôts throughout the kingdom. Early in 1915 the War Office recognized the Almeric Paget Massage Corps, and made it the official body to which all masseuses and masseurs engaged for service in military hospitals should belong. Members of the corps were recruited almost exclusively from those who held the certificate of the Incorporated Society, though a few members were allowed to join in special circumstances. Notable amongst these exceptions were those who held a certificate from one of the recognized physical training colleges. The interests of patients and the profession were finally safeguarded by the appointment of an Advisory Committee, and the admission of untrained or partially trained personnel was thus entirely prevented.

Further recognition of the work of the Almeric Paget Massage Corps was given in December 1916 when the word " Military " was added to the title of the Corps, and in January 1919 it became known, by Army Council Instruction, as the Military Massage Service.

Up to January 1917 members of the service worked exclusively at home ; but at this date, and till six months after the signing of the armistice, permission to serve in France and Italy was granted. Masseuses found their way even to Serbia and Salonika, and a regular service was instituted on board hospital ships.

In February 1917 a regular massage service was also inaugurated for the Navy, mainly at the instigation of Fleet-Surgeon A. K. Smith-Shand

In 1916 the Institute of Massage and Remedial Gymnastics was founded in Manchester, and, obtaining incorporation without the word "limited," it began holding examinations there. The Incorporated Society of London felt that a multiplication of examining bodies must tend to lower the standard, and, with a view to establishing a one-portal system, suggested amalgamation in 1917. After some delay, this was arranged, and in 1919 the two societies presented a petition for a Charter, which, as already stated, was granted in June 1920.

It has proved impossible to record the number of masseurs and masseuses who have been actively engaged in work for the wounded. The number employed by the Military Massage Service alone was as follows:—

January	1916	..	..	..	900
"	1917	..	..	..	1,200
"	1918	..	..	..	1,500
November	1918	..	..	..	2,000

The total number of camps was 19, and the total number of military hospitals 525 where masseuses were employed. This was exclusive of those hospitals which, having training schools of their own or directly connected with them, did work for the wounded.

The convalescent hospitals may be regarded as the connecting link between the hospitals and the command dépôts. A military school of massage was opened at the large convalescent hospital at Blackpool, and men of the R.A.M.C. were prepared for the examinations of the Incorporated Society of Trained Masseuses by a staff of instructresses, who were members of the Almeric Paget Massage Corps. As these convalescent hospitals were not intended for the treatment of protracted cases, the stay of patients in them was limited.

It was not until March 1916 that physical therapy was regarded as essential in every hospital called upon to treat a considerable number of wounded men. Thereafter its employment became more and more general, till by the end of the war it was universally adopted. Unfortunately only a few medical men had, prior to the war, interested themselves in physical treatment; and thus there was considerable difficulty in finding surgeons ready and able to take command of the technical work. At the same time the number of those masseuses who had pre-war experience was inadequate to supply the need. But the numbers of students admitted to training schools throughout the country increased rapidly, and the

special departments established for physical treatment soon supplied the medical men to take charge of them.

The aim of all physical treatment is restoration of function, and function generally implies voluntary effort. The application of massage demands nothing from the volition of the patient, and so it comes about that other means are usually essential. The realization of this truth by members of the medical profession marks a notable advance in medical treatment, and more and more medical men realize that "massage" should not consist solely of rubbing under one guise or another. The masseuses, to be fully equipped, must have a wide and ample education, and some training in anatomy has been proved to be essential. Not only is knowledge of muscle origins, insertions and nerve supplies required, but their action must also be fully appreciated, for it is no easy task to train a formerly paralysed muscle to work, and a long time must often elapse between the first evidence of renewed vitality and the day when the muscle is fit to take its place again in the movements of the limb.

Another point is the value of training afresh the lost co-ordination. Nowhere is this better seen than in the re-education of the limbless. It is now recognized more and more that re-education of the muscles in the stump of an amputated limb can confer inestimable benefit upon the patient. But more than that, it has been found that the application of Frenkël's theories can do still more, and a pitch of excellence not previously anticipated in the use of artificial limbs has been attained by the training of the muscle and joint senses and of the tactile sensation in the stump.

On the technical side, one great truth has been established, namely, that muscle strength cannot be built up merely by massage. This does not mean that the value of massage in cases of muscular weakness should be belittled. On the contrary, it is massage, and often massage alone, which can prepare and pave the way for the moment when the patient's muscles shall be once more completely restored by the revived power of spontaneous action.

During the war Colin MacKenzie published a book on muscle action, and his conception of utilizing gravity so that the posture of the part under treatment may assist active movement was of the greatest possible value in the early stages of restoring voluntary movement.

The recognized training in remedial and educational gymnastics in this country is that which is technically known as

"Swedish." The parallel bars and the weight and pulley find no place in the outfit of a "Swedish" gymnasium. Yet Colonel Deane, of Croydon, writes as follows of the parallel bars :—"The value of this apparatus may be judged when it is said that were a gymnast confined to one piece of apparatus for ordinary purposes, or were a medical superintendent who understood the application of gymnastics to disabilities restricted to one apparatus, unhesitatingly they would both select parallel bars."

In a previous generation, when Swedish educational and remedial gymnastics in this country were in their infancy, Dr. Wharton Hood fully realized the value of exercise as the one great essential to the restoration of function. His apparatus consisted almost entirely of the weight and pulley, arranged in various ways, and during the war this apparatus again found several notable adherents. Chief among these was Major Tait McKenzie, Professor of Physical Education in the University of Pennsylvania, who while serving in England did much to emphasize anew the value of this apparatus in remedial work, and with great ingenuity devised various ways of adapting it to the treatment of different injuries.

At the Shepherd's Bush Hospital a considerable amount of Dr. Wharton Hood's original apparatus was installed in the massage department and was incorporated in a combined apparatus which included a ladder, detachable vertical poles, a wrist and arm roller and rotater, and an adjustable sliding seat. Although the member of the staff who was in charge of the "exercise room" attached to the department had been for many years a prominent exponent and advocate of the Swedish system, yet it was interesting to note the increasing value she placed on the intelligent use of this apparatus.

Of Zander and pendulum apparatus but little was heard in England during the war. At the Grand Palais in Paris and at the Anglo-Belgian Hospital at Rouen it was in extensive use, but in this country it found few advocates. The initial expense of installation may have had an inhibitory effect, but this was not a decisive factor, for money was always to be obtained for anything that was really essential to the well-being or treatment of the wounded. Lack of advocacy of its merits was the only reason why it was not more extensively installed.

In pre-war days it was rare to find anyone who did not regard an open wound as a definite contraindication to massage treatment. Now it is an accepted fact that the skin being broken is no impediment, and that limbs with extensive open wounds can benefit very materially by massage.

The chief reason why massage, as a treatment to secure the more rapid healing of ulcers and open wounds, was not more generally recognized was the fear of causing infection or the spreading of sepsis. The war has done much to dispel this fear. It is true that a special technique is called for when an open wound is present ; but, granted the technique, nothing but good should follow.

In the matter of early mobilization, too, the treatment advocated by Lucas-Championnière found supporters. This consisted of massage to prepare the way for passive movement, which in its turn was a prelude to the commencement of active movement. Nearly everyone who has had experience of work amongst the wounded has, at one time or another, lost patience with a stiff joint which has refused to regain function, and impatience and disaster have often been found to go hand in hand. Time after time each worker has learned from bitter experience that increase of swelling, increase of pain, and decrease in mobility are sure and certain indications of abuse of treatment. But while forced movement in the form of "assistive" active movement has now acquired a definite place in treatment, in the form of an eccentric "resistive" exercise to the antagonists it has been found wanting. It required the united experience of countless workers—such as the war alone could supply—to establish beyond doubt the fact that the way to perform a forced movement is to do it with the assistance of the muscles which naturally perform it, rather than against the resistance of the antagonists.

In close relationship with treatment on these lines is the combination of massage, and all that this term implies, with treatment by splintage. The one is often the corollary of the other. At first sight it might seem that the opinions of Sir Robert Jones and of Lucas-Championnière were at variance, but this is not so ; for the latter's teaching was not aimed against splintage, or even against immobilization, but only against unrelaxed fixation. The combination of rest and movement is the key to success, and, looking back through the years of the war, it is easy to see how greatly the science and art of physical therapy have been advanced.

Remedial Exercises.

Physical exercises were used very largely during the war for their remedial effect, both physical and psychic, and as the war progressed the psychic side of the subject became better known and was utilized more and more. It is remarkable,

however, how limited was the scientific knowledge of physical training in this country before the war. Ling's teaching of the correlation of physiology and anatomy applied to physical training was known only to a few, although good pioneer work had been done by the women's physical training colleges at Dartford, Bedford and Chelsea, by the Royal Naval Physical Training School at Portsmouth and by the Army gymnasium at Aldershot. Few service experts were detached for their special work until wounds or sickness had rendered them unfit for active service. Consequently, many of the civil hospital establishments, possessing remedial exercise departments, had to be placed in charge either of doctors with little previous knowledge of the subject or of gymnasts of the army instructor type, whose education did not bring them into touch with the doctors. Later on, however, in many of these departments the services of thoroughly trained women from the above colleges were employed, and for special work on individual patients they succeeded admirably. Some medical officers considered that it was asking too much of them to place them in charge of large classes of soldier patients, because these often included a few men who resented the idea of being drilled by a woman, and required the discipline of an experienced man.

It will be seen, therefore, how great was the need for a civil physical training college in the United Kingdom, where both male lay instructors and medical students could take a long course of instruction and qualify in this subject. Perfect as the Swedish system of exercises is anatomically, it becomes irksome and monotonous to most, and the exercises have a greater value when given in the form of games, provided that anatomical requirements are properly studied. It must be remembered, however, that if an efficient British system of exercises is to be produced, it must be based on the broad principles laid down by Ling.

One danger to be guarded against by those who are arranging a clinic for remedial exercises, and who have to rely upon the advice of others, is that laymen who have taken the long course of instruction at Stockholm may have been taught very correctly without quite grasping the meaning of the principles laid down, and, after working independently in this country for a time, introduce innovations into their work which quite spoil it. Thus, much of the so-called Swedish gymnastic class work seen was really not Ling's system at all.

Fortunately for the sick and wounded, the enthusiasm displayed by all the workers in the physiotherapy departments

made up in a great measure for the lack of academic knowledge possessed, but harm was done as well as good.

Exact data and statistics of the carrying out of different forms of treatment were meagre owing to the overwhelming quantity of work, so that in all probability much valuable experience has been unrecorded.

At the outbreak of war, St. Thomas' Hospital was probably better equipped and staffed for the treatment of the injured by remedial exercises than most other establishments in the country. Dr. R. Timberg, assisted by a graduate of the Royal Gymnastic Central Institute in Stockholm, was in charge of the department, to which a school of physiotherapy was attached, where women received a course of tuition. It is at this kind of establishment that the very best work is performed, so that it may serve as a model for the similar institutions required by a great war. The following notes dealing with the subject of equipment, contributed by Dr. Timberg, are given almost verbatim.

The wounded began to arrive at St. Thomas' Hospital at the beginning of September 1914, and many of them were soon referred to the physical exercise department. The prevailing affection at this early date was septic feet. These patients needed little local treatment in the department, but it was rightly considered of importance to maintain them in good general condition by exercise, so as to fit them for an early return to the front.

The treatment in these cases consisted in regular lessons in Swedish educational gymnastics, for which the hospital provided excellent facilities, and daily instruction was given in the gymnasium to all military patients capable of taking part.

This type of case was in time replaced by more seriously injured men in gradually increasing numbers, until in the early summer of 1915 St. Thomas' was formally constituted the "Fifth London General Hospital," with about 500 military beds. This meant a very great influx of work to the physiotherapy department. Here massage and exercises were closely correlated, but it was not found possible to incorporate the electrical work in the same department.

One result of the intimate blending of massage and exercises is that a better view is gained of their relative importance and of the contribution of each to the ultimate result, and it is difficult to know where the line should be drawn between the two.

One prominent impression left on Dr. Timberg's mind was the futility of many of the elaborate mechanical contrivances which were devised for the administration of movements in cases of stiffened joints or other disabilities. Two inherent faults rendered the majority of them unpractical, if not useless ; first, the time and trouble involved in attaching the patient's limb to the machine, and, secondly, the facility with which the patient could avoid performing the exact movement intended.

An intelligent operator can much more quickly and efficiently guide and encourage the patient's efforts. All apparatus should be simple in nature, easy to arrange and not liable to misuse. On the other hand, it is only right to state that the Zander apparatus was extensively used at Netley for moving stiffened joints, and that Major Cooper, R.A.M.C., speaks highly of it.

The following equipment was found to be of the greatest advantage :—

(1) It is necessary to have a sufficient number of couches, technically referred to as " low plinths," which ought to be 17 in. high, the height of an ordinary chair, and 63 in. long by 25 in. broad. The top of the couch should be firmly and evenly padded and covered with leather. Both ends are best hinged for raising to any desired angle, one flap occupying 20 in. of the length, the rest of the couch consequently 43 in. In this way a comfortable seat is provided for the patient, and certain arm exercises can be carried out with advantage by the operator standing on the framework of the couch behind the raised flap that supports the patient's back. A great many passive as well as active leg exercises, both for hip and knee joints, also lend themselves to this sitting posture. Incidentally this plinth forms an ideal massage couch, and it would have saved much fatigue and backache if it could have been adopted in all the war hospitals instead of the ordinary beds that were so largely used.

(2) The " high plinth " or couch should be 32 in. high, 57 in. long, with a strong and firm framework at the bottom, 25 in. broad, and have a top padded in the same way as the low couch, but varying in width along its length from 18 in. to 12 in. It is chiefly used for sitting astride, the feet then being inserted into loops of leather strapping fixed to the bottom framework at heights varying from 8 in. to 12 in. off the ground, to suit the length of the patient's leg and, like the width of the top, to suit the varying degree of mobility in the hip joints.

This high plinth has a more restricted use than the low plinth, so that a few will suffice, but it is of great assistance in carrying out many trunk exercises, the legs and pelvis being fixed by the so-called "ride sitting" position, thus confining to the trunk itself the various movements such as bending forward, backward and sideways, and twisting.

(3) Stools of various heights are also required in the exercise room. They should be strong, steady wooden structures with a flat top and no back and should measure 20 in. square.

The most convenient heights were 22 in., 17 in., and 9 in. These stools were used sometimes by the operator and sometimes by the patient.

(4) Rib-stalls (also called "wall-bars") consist of broad ladders fixed in the wall, with closely set rungs, 5 in. from centre to centre, and reaching to a height of about 8 ft. The width is of less importance in the case of isolated ladders of this description, but if two or more are joined together they ought to be not less than 36 in. wide for the class of patient under consideration, so that one performer shall not interfere with his neighbour. The number of these "ladders" should be half that of the number of patients likely to be attending the exercises at one time.

Rib-stalls are much used for climbing and hanging exercises, and are of real importance, but they may be to some extent replaced by the "beam."

(5) The beams, of which there should be two, one above the other, are strong wooden bars, each end of which is fixed in upright standards so that they can be adjusted easily and quickly to any desired height. This is simply arranged by holes being bored through the standards, three or four inches apart, through which a metal pin is inserted to carry the beam.

The beam is used like a horizontal bar, to be gripped by the hands, and as more or less of the body weight is supported by the arms, the elbow and shoulder joints can be exercised and expansion of the thorax assisted. Being freely adjustable in height, the beam can also be used to support the patient's body in various powerful trunk exercises. The effect of two beams being available adds much to the varied utility of this appliance, because the lower one can be used as a support for the patient's body while he hangs from the upper one. One edge of the beam is rounded for gripping, the other being flat, so that it may be turned up for the practice of balance exercises. If the size of the room permits, more than one such section

ought to be fitted. The beam to some extent may replace the "horse."

(6) The low bench is strong and steady and is 12 in. high and 12 in. broad on the top. It should be provided with a flat narrow bar at the bottom, so that with the bench turned upside down it can be used for balance-walking exercises.

(7) Window ladders, which were included at St. Thomas', are regarded by Murray Levick as one of the most essential forms of apparatus in the re-education of the disabled. The exercises consist of climbing in and out of the squares, up, down, horizontally, diagonally or vertically, with hands or feet first as may be directed, and they give rise to a great variety of movements of both limbs and trunk. The "ladders" provide opportunities for all-round muscular activity and suppleness, and a patient at all advanced on the road to recovery is easily made to forget his disabilities and to carry out movements that he might otherwise think are beyond his power. Classes can follow one another in a rapid stream.

(8) A pair of standards with a lath or rope placed across on adjustable pegs is of use for stepping or jumping over.

(9) Sculling apparatus is of great utility. It is a variation of the sliding seat of an outrigger racing boat, but with longer runners, so that a range from full extension to complete flexion of the knee joint can be achieved.

(10) A stationary bicycle is of obvious use.

(11) The wrist roll is a rod used for gripping by either hand and rolling round either by flexion or extension of the wrist. It exercises the gripping muscles and increases the mobility of the wrist.

Indian clubs have been found of the greatest use and are highly recommended, especially for improving the suppleness of wrists, elbows, and shoulders.

In starting a gymnasium for remedial exercises, however, it would probably be better to leave the equipment to be evolved by those in charge of the treatment, in accordance with their own methods, and much needless expenditure would thus be saved.

As to the selection of cases for exercises, either in a special exercise room or general gymnasium, it is obvious that in any general military hospital, and to a less extent in an orthopædic centre, there must be a vast number of patients who are not fit for exercises in the ordinary sense of the word, yet can derive benefit from movements given to them with care even when they are in bed, and it is a very important consideration

that a muscle can be exercised without its producing any movement of a joint. For instance, when the knee-joint is fully extended, voluntary contractions can be elicited in the quadriceps extensor cruris without any movement of the articular surfaces.

Assuming that a patient who has suffered from a knee injury has passed through the stage in which such primitive exercise alone is possible, and that he is continuing to receive massage and appropriate electrical treatment and is allowed to move about in a wheeled chair or on crutches, the low plinth will form a very convenient seat for the carrying out of knee bending and stretching, whether it is a question of passive movement, guiding and assisting the patient's own movements, or resisting them to increase his muscular work. This is a case too in which the rowing apparatus will be of great use. Once placed on the sliding seat, such a patient may safely give himself his own exercise, as the movement is purely one of flexion and extension without any risk of side movements. It is often surprising to the patient himself to find how soon the range of mobility is increased. From this he can go on to the stationary bicycle, and thence to free standing exercises.

What has been said of the stiff knee applies to the treatment of various disabilities, and is intended to show the lines on which a patient can be taken through the various stages on the road to restored mobility.

At the Liverpool Pensions Hospital Major W. H. Broad, the officer-in-charge, made a practice of seeing each patient in the presence of the gymnastic instructor, to whom he gave detailed instructions as to the treatment. This is a very important matter. Patients should never be passed on to a lay gymnast, however clever he may be, with a bare request for "exercises." Patients who were capable of participation in a general class did individual exercises suited to their special disabilities before joining it each day. It was noted here that a routine of "drill" exercises without the variation of games soon palled, and many varieties were introduced, the most popular being "basket ball." Major Broad mentions the case of a patient who had his internal semilunar cartilage excised. Five days after the operation massage was begun; ten days later, gentle movements; on the fourteenth day he began treatment in the gymnasium, and on the twenty-first day after the operation he jumped 4 ft. 10 in. high, taking off with the injured leg.

At the Shropshire Surgical Home, superintended by Miss A. G. Hunt, the organization and application of remedial exercises were particularly good, and the arrangements in it may be detailed as indicating the requirements for similar establishments. The treatment was based on the Swedish system of remedial exercises, and was designed to restore the voluntary use of an affected part in the shortest possible time without over-tiring, and to exercise to the fullest extent the concentration and volition of the patient. The average time for each case was half an hour. The cases were divided into three groups.

Group I.—The re-educative group, composed of patients who had attained a certain amount of voluntary power, and were beginning to discard splints and leave off massage treatment, included cases of nerve injuries, tendon transplantations and functional disabilities. Each of these cases received the individual attention of a gymnast, who directed movements suitable to the case, on the principle of :—

- (1) Gravity assisting movement.
- (2) Gravity neither for nor against.
- (3) Against gravity.
- (4) Resistive movements.

Group II.—This group was composed of cases with stiff knees, stiff ankles, stiff shoulders or flat feet.

These were arranged in squads and went through tables of exercises in class formation on Swedish lines.

Indoor gymnasium games, such as basket-ball, bean-bag and foot races, were used as much as possible, and played an important part in the mobilization of stiff joints, in warming up the limb during cold weather, as well as in restoring muscle tone and innervation to the affected joint.

Group III.—This group was composed of patients who could take part in organized outdoor games. Football, hockey, cricket and lawn tennis were played in season, and golf all the year round. The games were managed by a committee, consisting of both staff and patients, and different events were arranged for each day of the week. As the staff of the special treatment departments were able to take an active part in most of the sports, an excellent opportunity was provided for judging a patient's capability and endurance under the best conditions, and the knowledge thus gained was fully used in the routine gymnastic work. Golf especially gave very good results, and was taken up with the greatest enthusiasm by the patients, though very few of them had played previously. Going over

rough ground was a strenuous test for leg cases, but it was quite a usual thing for a patient to play from eighteen to thirty-six holes in the course of the day set aside for that purpose.

At the special military surgical hospital, Edmonton, in addition to gymnastic classes in a large gymnasium, special attention was given to the subject of re-education, the work being carried out in two small rooms reserved for the purpose. The apparatus was very simple, use being made of such ordinary articles as pins, bags or bowls of sand, tennis balls, marbles, skipping ropes, footballs and so on. There were two instructresses, one from the Dartford Physical Training College, and one from the Swedish Physical Training College, Bournemouth.

In dealing with functional cases, a note was made of the particular muscles requiring attention. The patient did simple exercises with his sound limb to remind him how the movements should be made, and was then told to repeat the movement with both limbs. This proved to be a successful principle.

When the time arrived for beginning the re-education of patients recovering from nerve suture, simple everyday movements were taught. For instance, in a case of ulnar nerve injury, instead of making the patient spread out and approximate his fingers in purposeless repetition, he was made to lift handfuls of sand out of a bowl, and to prevent it trickling through his fingers.

It has been difficult to get any clear account of the special methods adopted by individual experts in re-education. There was evidently more in their personality than in the methods employed. An example of this is the long list of successes attained by the masseuse who specialized in this work at the special military surgical hospital at Shepherd's Bush. She could succeed in a week, after others had wasted months of useless diligence.

The medical profession has been inclined to regard the treatment of disabilities by exercise as one that can be learnt in a few weeks or a few months, but even a doctor of more than the average intelligence needs to undergo a long course of practical instruction at an age when he can do the exercises himself, before he can realize their full meaning, possibilities and limitations.

In addition much was learnt on the psychical side of the subject. The psychic influence of games and other exercises was utilized on a very large scale in the armies in France and at home, and was carried out almost entirely by combatant officers and N.C.O.'s.

There were many combatant officers and N.C.O.'s employed in handling the convalescent soldier, and these, though they had little technical knowledge, used their common sense and accomplished a great deal. Some worked in the remedial exercise hut and others on the parade ground, and by their united efforts they rendered thousands of men fit to retake their place in the line. They also made more useful citizens of those whose disabilities relegated them to labour units or necessitated their discharge from the army. The sphere of influence of these instructors extended to all places where convalescents were trained after leaving hospital.

With a lead from the convalescent depôts in France, those dealing with physical training in England soon saw that the repair of the convalescent and his hardening for further service did not merely lie in the healing of wounds and re-education of muscles. It was also necessary to keep the men cheerful, and thereby materially assist in their recovery.

It was chiefly the duty of the physical training officers and N.C.O.'s to handle the convalescents in such a way that they obtained the goodwill of all ranks. The methods adopted were simple and often unorthodox. In the hut the individual was interested in his own case, was encouraged in his efforts to make muscles respond and to carry out movements which had been second nature in civilian occupation; competitions were arranged between those with similar disabilities in simple—often childish—games, where a movement despaired of as unrecoverable came unconsciously. Many apparatus were invented to assist these methods, but success more often depended on the personality of the instructor than on the apparatus used.

On parade it was again a question of the personality of the instructor, who led the men to think and act as men rather than as cripples. The means used were physical exercises, games and dancing. The men came to look on their time in convalescent hospital as a period of real enjoyment, for they forgot the exercises which were sandwiched in between the games. The type of games was so varied that it was possible to suit every degree of convalescence. The exercises were simple, but always chosen for a particular purpose, and called for much or little concentration according to the stage of convalescence. They were often disguised in game form. Dancing was not of the ballroom description but often of the style of the old English country dances or of the Scottish reel or Irish jig. Regular officers, seeing the work for the first time,

generally asked, "What of discipline?" If they stayed and looked deeper they got their answer, for there existed a very fine discipline.

The principle was to train men again to real military discipline. The first lesson was to obey the simple rules of a game and to play it fairly. In and out of parade hours the officers and N.C.O.'s, supported by the permanent staff of the establishment, organized games, sports and recreations which would appeal to all. Competitions were so arranged as to call forth *esprit de corps* in hut, company, group or division, since it was well-nigh impossible to maintain the regimental spirit where such a mixture of units existed. All this was remedial work. In England these methods were adopted late, but they had the effect of making men sound in mind as well as body, and there was no lack of testimony that the reinforcements composed of men who had been wounded were hard, well-disciplined men of excellent *moral*.

Those responsible for the handling of convalescents in France had based their methods on a belief in the love of games possessed by the British, and in 1916 properly organized sports and recreations were authorized for the troops. Physical activity on these lines came to be used as a tonic medicine for trench weariness. Once out of the line, remedial treatment of the mind came as a first consideration, and during the whole period of recuperation of a spent body of troops games played a prominent part in the day's programme.

The subject was known as "Physical and Recreational Training," and came to be part of the work of the Army Gymnastic Staff. The training of specialists and regimental officers and N.C.O.'s on the correct lines and the provision of gear and grounds created a large organization, and Colonel R. B. Campbell, who was known to the troops for his inspiring lectures on the bayonet, took hold of and developed the idea of recreation as an organized part of a soldier's occupation. This treatment assisted to a great degree in maintaining the *moral* of the British troops in all theatres of the war. The germ of the idea was eagerly seized upon by those who had to deal with the resuscitation of the soldier wounded in mind as well as in body, and the results justified the special attention of the medical services to this source of curative as well as preventive treatment.

CHAPTER XIII.

ORTHOPÆDIC TREATMENT OF MUSCLES, JOINTS AND BONES.

IN the early days of the war the greatest problem which surgeons had to face was the severe and almost universal sepsis. This was seen after every type of wound, whether of the small punctured gunshot variety or the large gaping shell wound, and its severity did not depend on the extent of the damage done. Loss of function was frequently seen after these wounds, but when it was found that the best method of preventing or limiting sepsis was a complete early excision of all damaged tissues, then functional loss was sometimes the result of the treatment itself. A single muscle or a group of muscles which had been injured might be excised completely, leaving a limb in which function could be restored only by the abnormal aid of the remaining healthy muscles.

This group of cases added very considerably to the large number of patients in whom, owing to a nerve wound, one or many of the movements in a limb had been lost. Here the first object was to suture the injured nerve or free it from scar, and where this could be done the prognosis for ultimate functional recovery was undoubtedly good, but unfortunately complete recovery of function did not always take place. When, from any reason, the recovery of function did not take place in the muscles supplied by an injured nerve, the problem to be faced was almost identical with that presented in the case of excision of a group of muscles for injury. The restoration of function in such a limb might to a slight extent be brought about by the application of some apparatus, applied externally, which would retain the limb in the position of greatest functional utility, or by means of a spring, would restore the limb to this position after movement by the active muscles or gravity. Such apparatus is necessarily cumbersome and irksome, and the more movement allowed by it the more likely is it to require frequent repair of its many springs and hinges.

TENDON TRANSPLANTATION.

Another method of treatment consisted in making use of some of the active muscles from one group and by transferring their lines of action and points of insertion so to change their function that they replaced the action of the paralysed or

absent muscles. It was found in practice that the muscles of the upper limb, which are more specialized in action, act better when transplanted than those of the lower limb. This seems to be due to the more specialized nerve control, whereby one muscle may be taken away from the muscles normally associated with it and when transplanted may act independently.

Almost all the experience in tendon transplantation previous to the war had been gained in the study of cases of infantile paralysis, in which this operation was comparatively common, although tendon transplantation for musculo-spiral paralysis had been suggested by Sir Robert Jones and performed by him about the year 1905. Tendon transplantation in these cases may be defined as the means of restoring voluntary movements which have been lost owing to the irretrievable destruction of the muscles, or of the nerve supplying the muscles normally producing these movements.

Tendon transplantation or tendon fixation is fortunately more or less applicable to every case of peripheral nerve injury, both in the upper or lower limb, but in considering the various transplantations the aim and object of the operation differs somewhat with the situation of the injury. Thus, in the upper limb, the most important aim is to secure mobility with the greatest amount of stability compatible with this voluntary power. In the lower limb, however, while active movement is desirable from every point of view, yet the chief end to be attained is stability of the limb for weight-bearing purposes.

Before considering in detail the various tendon transplantations which can be adopted, certain rules must be clearly understood and closely followed if a successful result is to be obtained from the transplantation. First, the joints upon which the transplanted tendons are called upon to act must be rendered as mobile as possible. Secondly, the muscle and tendon to be transplanted must be of sufficient strength to accomplish the action for which they are to be employed. Thirdly, the transplanted muscle with its tendon must pursue a straight course between its origin and insertion, and should not work obliquely or round an angle; and fourthly, the transplanted muscle must be attached under slight tension.

Destruction of the musculo-spiral nerve, with its consequent crippling paralysis, is a comparatively common injury after a shattering wound of the arm, and here tendon transplantation is of the greatest use. The position of maximum strength in the hand is the position of dorsiflexion of the wrist to an angle

of 40 deg. to 45 deg. and this is the position in which the hand is held whilst doing any form of manual labour. In this position the extensors of the wrist are in a state of contraction whilst the flexors are in a state of relaxation ; consequently it may be said that the full power of the hand and fingers can be employed without calling into use the flexor carpi radialis, flexor carpi ulnaris or the palmaris longus, and these three muscles are found to be of the greatest use in restoring function to the paralyzed wrist and finger extensors. Different methods of using these muscles are employed by surgeons, but, in whatever way they are used, either by themselves or in association with the pronator radii teres, the object is the restoration of active dorsiflexion of the wrist and extension of the fingers. Usually the pronator radii teres is approached through an incision close to its insertion into the radius and after being completely freed from the bone is inserted into the extensor carpi radialis longior and brevior under cover of the supinator longus tendon. This operation is performed whilst the wrist is fully dorsiflexed and the fingers extended, with the muscles under slight tension.

The tendons of the flexors carpi radialis and ulnaris are then divided close to their insertion into the carpus, and, after being passed underneath the skin round the outer and inner borders of the forearm respectively, they are inserted into the extensors of the thumb and fingers. Usually the flexor carpi radialis is passed through the three extensors of the thumb, and the flexor carpi ulnaris through the extensors of all the fingers. Occasionally, when it is found to be present and to be of good strength, the palmaris longus is similarly attached to the extensor longus pollicis.

When the pronator radii teres muscle is not used the flexor carpi ulnaris may be attached either to the extensor carpi ulnaris or to the base of the fifth metacarpal bone, and the flexor carpi radialis and palmaris longus to the thumb and finger extensors.

The method first described, in which the pronator radii teres is used to produce dorsiflexion of the wrist, is the one which has given consistently good results, and may be looked upon as the recognised operation under these conditions.

Destruction of the posterior interosseous nerve is met with comparatively often where there has been a wound of the upper part of the back of the forearm. This nerve is so short and so quickly breaks up into its many minute branches that operative restoration is usually impossible. It is found that

even when the different branches have been isolated, and apparent anatomical restoration has been effected, recovery does not usually take place in any of the affected muscles. The problem then is almost identical with that of the destroyed musculo-spiral nerve, except that in this case active dorsiflexion of the wrist is retained because the extensor carpi radialis longior is supplied by the musculo-spiral nerve before its division. The only modification in the treatment by tendon transplantation is that the pronator radii teres muscle is left *in situ*, whilst the other muscles, flexor carpi radialis, flexor carpi ulnaris and the palmaris longus, are used as previously described, to produce active extension of the thumb and fingers.

There are several methods of inserting one tendon into another, and the method used depends largely on whether the tendon to be transplanted is larger or smaller than the one into which it is being inserted, but in whatever way this is accomplished, care must be taken that the rough cut end of the tendon is so covered over that no adhesions form between it and the neighbouring structures.

In the case of destruction of the median nerve in the arm, which is frequently injured either by itself or in association with other nerves, end-to-end suture of the divided nerve is usually possible after complete flexion of the elbow and wrist joints. When, however, owing to the large amount of nerve tissue destroyed or to bony ankylosis of these joints, suture of the divided nerve is found to be impossible, tendon transplantations can undoubtedly improve the function of the hand. The loss of use in the hand is due chiefly to the loss of power of flexion of the thumb and index finger, and usually slight loss of power of flexion of the middle finger in addition. A very marked improvement of function can be obtained by transplanting the extensor carpi radialis longior into the flexor longus pollicis, and suturing the two outer inactive tendons of the flexor profundus digitorum into the two inner active tendons of the same muscle. By this means function is restored in a remarkable manner, and the patient can perform almost all the normal movements of the fingers and thumb, although unfortunately the loss of sensation over the index and middle fingers, and to a lesser extent over the thumb, remains a permanent bar to a complete recovery.

When both the median and ulnar nerves have been irretrievably destroyed, restoration of movements is much more difficult. In this case the hand is usually fixed in a position of well-marked claw hand, with dorsiflexion of the

metacarpo-phalangeal range of joints and flexion of the interphalangeal ranges. In order to relieve this condition the extensor carpi radialis is transplanted round the outer border of the radius, as in the case of uncomplicated median paralysis, and is inserted into the flexor longus pollicis. This permits of flexion of the tip of the thumb, but this flexion produces a comparatively poor functional result, as the base of the thumb is not fixed and the thumb cannot be apposed to the fingers. In order to correct this, Sir Harold Stiles has proposed the fixation of the carpo-metacarpal joint of the thumb, and this addition has been employed by him with success. Similarly the index finger alone, or all the fingers, may be ankylosed in flexion in order to permit the mobile thumb and the fixed fingers to be used for grasping.

In nerve lesions causing paralysis round the shoulder girdle, tendon transplantation has unfortunately not proved to be of much use, but it is found that with a mobile controlled scapula a marked improvement in function results from the operation of arthrodesis of the shoulder.

As has been already stated, the muscles of the lower limb are not so specialized in their function as those of the upper limb, which are under more separate nerve control, and hence transplantation of any particular muscle does not usually lead to such a marked improvement in the function of the limb.

When the action of the quadriceps extensor muscle is lost, either from destruction of muscle tissue or from lesion of the anterior crural nerve, the biceps tendon may be transplanted from the posterior aspect of the thigh and inserted into the patella. When this is done, contraction of the biceps causes a strong extension of the leg, but as the line of pull of the active tendon is not straight, the patella tends to be pulled on to or even over the external condyle of the tibia. This tendency is especially marked if there is any valgoid deformity of the leg, and therefore, instead of using only the biceps tendon for transplantation, the semitendinosus should also be used, so that the pull on the patella may be in the same direction as it was when the quadriceps was acting.

Paralysis of the muscles supplied by the external or internal popliteal nerves is comparatively common, and when it is found to be permanent less can be done to restore the normal function of the foot than in the case of the corresponding paralysis of the upper limb.

Transplantations of muscles from the flexor to the extensor aspect of the limb, or *vice versa*, which in the case of the forearm

lead to almost complete restoration of function, do not unfortunately lead to a similar happy result in the case of the leg. For that reason the line of treatment to be adopted is the correction of any deformity and the fixation of the foot in such a manner that the recurrence of this deformity is rendered impossible.

In patients suffering from permanent paralysis of the muscles on the anterior aspect of the leg the dropped foot may be treated by the following operation. The tibialis anticus and peroneus brevis tendons are cut close to the junction of their fleshy and tendinous bodies. The tendon of the peroneus brevis is left attached to the fifth metatarsal bone and after being passed in front of the external malleolus is brought to the opening through which the tibialis anticus tendon has been divided. The two divided tendons are now passed transversely through a hole bored through the tibia about $2\frac{1}{2}$ –3 in. above the ankle joint and after passing completely through the bone the two free ends are sutured tightly together whilst the foot is held in a position of dorsiflexion at an angle of 75 degrees to the front of the leg.

The result of this operation is that the ankle can still be completely dorsiflexed whilst the tendon fixation prevents the recurrence of the deformity and thus the spring of the foot and ankle is left unimpaired.

When the internal popliteal muscles are paralysed the tendo Achillis may be split vertically and one half of the split tendon after it has been divided from its attachment to the fleshy part of the muscle is passed through a hole which has been drilled in the back of the tibia. This portion of tendon is now firmly fixed to the bone whilst the foot is held at right angles to the leg, thus permitting of a firm stance and a raising of the heel in walking.

STIFF, ANKYLOSED AND FLAIL JOINTS.

The fixation of limbs which was required for the treatment of the severe compound fractures met with during the war resulted frequently in a more or less severe type of rigidity in the neighbouring joints. The cause of this can be easily understood when one realizes how infection spread through the muscle and fascial planes which bound the muscles and tendons in their sheath and fixed them to the shafts and articular ends of the bones. The density of these adhesions varied very markedly, and the graver types were seen in

those cases in which no attempt had been made at either active or gentle passive movements of the neighbouring joints during the course of consolidation. The attempt to break these adhesions suddenly by forced movement of the joint, either with or without an anæsthetic, frequently resulted in a tragedy, for the prolonged fixation of the limb always produced a marked atrophic change in the bones, so that a refracture or the tearing off of a bony prominence often resulted.

There are two ways in which a safe attempt may be made to bring about mobilization in this class of case :—

- (a) Gradual flexion on a splint in successive short stages.
- (b) Forcing in successive stages under anæsthesia, with rest in splints during the intervals.

Both these methods are suited to the stiffness of prolonged immobilization, traumatic arthritis, and cases in which suppuration has occurred about the joint.

Joints which will not yield at all to manipulation under an anæsthetic will often do so when subjected to the influence of gravity assisted by a bandage. Furthermore, in a joint such as the elbow a flexion which cannot be brought about in safety by one manipulation can often be achieved by continuous stretching of the shortened structures. This may be illustrated by taking the elbow and knee as examples, because a most important and practical principle is involved.

In the presence of an old arthritis, or an old dislocation backwards of the forearm, forced flexion under anæsthesia may result in a gain of only 20°. If the arm is then left free, it will almost certainly lose the amount which has been gained, but if the elbow is firmly fixed in the position of greatest possible flexion it will be found that in a few days a second attempt at flexion will result in a further gain, as the structures which were previously preventing movement have now been stretched by the continuous pressure. It is usually possible by following this line of treatment to obtain the amount of flexion desired, as the tightened ligaments at the back of the elbow react to pressure in the same manner as scar tissue.

The same principle will obtain in the case of the knee, but in the attempt to flex a straight knee there is the advantage of the action of gravity. If the knee admits of, say, 15 deg. of flexion, a long posterior splint is applied, set at an angle of 15 deg. more. The limb is bandaged to this, and when the extra 15 deg. have been gained, the knee is kept at rest on the splint for a few days in order to relieve strained tissues. The bandage is then removed from below the knee, which is

allowed voluntary movement in the direction of full extension. When this has been secured the splint is bent another 15 deg. and the procedure is repeated. This is continued until sufficient flexion is obtained to enable the joint to be more vigorously exercised, first by active and then by passive movements.

Positions in Ankylosis.

In the presence of sepsis or severe injury in the neighbourhood of a joint in which there is the slightest chance of ankylosis occurring, the joint should always be fixed in the position of maximum utility. In deciding what this particular position of the joint should be, consideration must be given to the type of work which the patient will afterwards perform, but in the majority of cases it is found that the position of maximum utility is now clearly defined for each particular joint.

Shoulder Joint.—The arm should be abducted to about 60 degrees from the side. The elbow joint should be slightly in front of the coronal plane of the body, so that when the elbow is at right angles and the forearm supinated, the palm of the hand is towards the face. The arm is placed in this position while the scapula retains its normal position of rest. In this position the hand can be easily made to reach the mouth by merely bending the elbow. Again, the humerus being fixed at this angle to the scapula, the arm can be lifted a considerable height by scapular action; pockets can be reached; a glass of water can be carried to the mouth without spilling its contents, and various essential acts can be performed with ease. In this position of fixation of the shoulder joint, the movement which has been lost in the joint itself is to a large extent compensated for by increased range of scapular motion, and for this reason it is essential that there should be no fixation of the scapula on the chest wall. When this has occurred, fixation of the arm in abduction is more detrimental than beneficial in its use.

Elbow Joint.—Before deciding the angle at which the elbow joint should be fixed, the patient's profession or work should be considered, and a consultation held with him in order to obtain his views. The greater number of men prefer an ankylosis at about a right angle. If both elbows are ankylosed it is best to fix one at slightly less and the other at slightly more than a right angle. The ankylosis commonly met with at about 130 degrees is functionally bad.

The position at a right angle enables the patient to move his hand to his mouth, button his clothes, brush his hair, and reach across a table. At an angle considerably less than 90 deg. it is more easy to get the hand to the mouth and to various parts of the head, but limitations in other directions more than counter-balance these advantages.

Forearm.—The forearm should never be fixed in a position of pronation. If a condition—*e.g.*, great comminution of the upper or lower ends of the radius and ulna—exists in which ankylosis is likely, then the forearm should be fixed midway between pronation and supination. If the condition will not lead to ankylosis, then it is best to ensure full supination from the outset, because pronation is readily regained, while supination of a prone arm is most difficult to restore.

Wrist Joint.—Injuries of the wrist joint are very frequent, and the golden rule in regard to their treatment is that this should be carried out with the wrist in a position of dorsiflexion. The great functional advantages of this position over that of palmar flexion can be easily demonstrated by anyone. There are, however, two exceptions to this rule, and these are in regard to the treatment of Colles' fracture and dislocation of the semilunar bone of the wrist joint.

A Colles' fracture can usually be most efficiently retained in position after reduction of the deformity by slight palmar flexion and full adduction, whilst the semilunar bone is so constructed that dislocation can only occur forwards, and therefore a temporary flexion of the wrist is advisable after reduction, if this can be accomplished.

The great advantage of dorsiflexion is that in this position the grip of the fingers is strengthened, although even from the æsthetic point of view dorsiflexion is indicated. A palmar-flexed wrist is always an eyesore. Care must be taken that the dorsiflexion splint is not allowed to slip downward, otherwise the metacarpo-phalangeal joints will be hyperextended, a condition which may give rise to serious disability.

Hip Joint.—Ankylosis should be secured in a position of very slight abduction with the thigh extended and with very slight outward rotation. The common deformity in ankylosis of the hip is flexion, adduction and internal rotation, which is the characteristic position in which the untreated tuberculous hip joint is found. It is accompanied by an ugly limp and a certain degree of lumbar lordosis. Adduction deformity brings the limb too near the middle line, interferes with the normal position of the sound limb on walking, and, by producing abduction of the sound limb, with a free swinging gait.

If the hip joint be ankylosed in the fully extended position, lordosis and the consequent trouble from backache are avoided, and there is freer pelvic movement in walking if the thigh is slightly abducted. The limb should also be very slightly rotated outward, to avoid the unpleasant lift of the pelvis as the patient rises on his toes when walking. Walking is easier if the toes are not pointed straight forward.

Knee.—In ankylosis of the knee, the joint should be in the extended position. Good reasons may be given in favour of slight flexion from the point of view of elegance in repose and that of ease in mounting stairs. Due weight should be given to these points, but in war injuries the straight position obviates many risks. Ankylosis is not always bony, and the incidence of body weight on a slightly bent knee, unless the ankylosis is sound and bony, will increase the flexion. The position, therefore, is mechanically a weak one for carrying the body weight. Even when bone is forming, its complete consolidation is sometimes a slow process, and if the surgeon places such a consolidating knee in a flexed position the degree of ultimate flexion is often greater than he would wish. The advantage of increased strength and stability ensured by an extended joint will outweigh all other considerations, although it must be admitted that in taking a wedge from a knee for bony ankylosis in a badly flexed position, it is an open question whether a position of slight flexion may not be indicated.

Ankle.—At the beginning of the war, ankylosis of the ankle joint at a right angle was considered to be the best possible position. On examination of a large number of cases, however, it would seem clear that where ankylosis has occurred at the tarsus or at the joints of the toes, the foot should be fixed in a position which is a few degrees more acute than a right angle. This enables the patient to walk with the minimum of strain upon the front part of the foot. The ankle should be in such a position that neither valgus nor varus should be evident, but if this cannot be obtained, then a slightly varoid deformity is preferable to the usual valgoid position.

Treatment of Ankylosis.

The consideration of true or bony ankylosis resolves itself into the distinction between ankylosis in a good position and in a bad position, and to the indications for and methods of treatment. It is but seldom that ankylosis in good functional position requires treatment, especially when it follows upon war injuries, in which a serious danger of latent sepsis always lurks.

True Ankylosis of the Shoulder Joint.—If a shoulder is ankylosed in the correct position few surgeons would wish to alter it. As a rule no operation can produce an improvement of the functional result in the case of a sound bony ankylosis of the shoulder joint in the position already described as that of maximum utility, and usually very special circumstances, such as a fixed scapula or a limited synostosis of the joint with no bony outgrowth and a clearly defined head, may be said to be the only reasons for altering this rule. In spite of such exceptions it should be emphasized that a shoulder ankylosed in good position produces the best functional result.

Where there is true ankylosis of the shoulder in a bad position there are two operative procedures: (a) osteotomy and (b) resection.

Osteotomy through the neck of the humerus is usually demanded. It is as successful in improving function as is osteotomy of the upper part of the femur. An incision is made through the anterior fibres of the deltoid, and a section through the bone is effected by a chisel. The operation should be conducted with care, a sand-bag being placed behind the shoulder. The arm should be fixed for a few weeks in the position of election. A range of scapular movement may thus be secured which allows of easy feeding and of abduction to well beyond the right angle so that the hand can reach the pockets, and with a little practice the collar can be fastened. The arm should not be rotated too far outward. This operation must not be performed in any case where, owing to other injuries of muscles, the shoulder cannot be shrugged, or where the rotation of the scapula is interfered with.

Arthroplasty, or excision of the shoulder, is sometimes a success and often a failure. It is indicated where the scapula is fixed and where a good deltoid is found. It is contra-indicated where a large mass of bone is in the axilla. The best routine incision is the anterior one between the deltoid and the pectoralis major, curved upward and backward over the shoulder in order to ensure an exposure of the deltoid and acromion. After removal of the head of the humerus, a flap of subcutaneous tissue and deep fascia should be turned downward and left hanging by a pedicle so that it can be passed round the stump of the head and sutured in position. The arm should then be fixed on an abduction splint in the position of right-angled abduction, and massage with voluntary movement from the splint begun early. A useful simplification of this operation has been made by Stiles, who, instead of using a fascial flap,

rubbs Horsley's wax into the rounded end of the humeral shaft. If in addition to the ankylosed shoulder, stiffness of the arm and fingers is found, these complications should be treated first of all before the operation upon the shoulder joint.

The conditions in which operations to obtain mobility may be considered are :

- (a) Where the deltoid is acting well, but the elevators of the scapula are destroyed.
 - (b) Where the contour of the head of the humerus is not obliterated.
 - (c) Where mobility at the expense of strength is desired.
 - (d) Where the glenoid cavity and the acromion are absent.
- The question of mobility should not be considered :
- (a) Where the deltoid or the muscles attached to the tuberosities are destroyed.
 - (b) Where a mass of bone is present in the axilla due to comminuted fracture.
 - (c) Where strength is preferred to mobility.
 - (d) Where an ankylosis in good position exists.

An arthroplasty of the shoulder is contra-indicated where the muscles governing the scapular movements do not act.

From observation of cases examined at various centres, it is certain that for a working man an ankylosis in good position provides the soundest functioning limb.

Faulty Ankylosis of the Shoulder.—Correction of this is frequently indicated, as so many shoulders have been allowed to ankylose in adduction with a certain degree of internal rotation. Correction can usually be effected by a simple osteotomy, but this should only be done where there is bony ankylosis—never if ankylosis is fibrous, for then the weight of the arm always causes the deformity to recur. If there is a great deal of thickening at the upper end of the humerus it may be necessary to remove a wedge of bone with its base outward. As a rule, however, a simple osteotomy suffices, and it is best to do this through healthy bone if that can be found sufficiently high up. The incision should be made anteriorly, for although the deltoid is not of much importance where ankylosis exists, it is not advisable to interfere with branches of the circumflex nerve by making the incision on the outer side. After the operation the arm should be fixed and maintained at the appropriate angle.

True Ankylosis of the Elbow.—The relative advantages of operating for mobility or for fixation are still open to discussion. It is only after a clear explanation to the patient as to the

possibilities and danger that a definite conclusion can be reached. The surgeon is often asked to stiffen a mobile weak elbow and to mobilize a strong fixed one. Function in the one case will depend on strength; in the other, on mobility. Given the assurance of free movement and full strength there can be no question of the superiority of a pseudarthrosis. A perfect result is, however, rarely seen. In a large proportion of cases a varying degree of lateral mobility is found, and a certain degree of loss of strength which prevents the lifting of heavy loads.

Men who do not require the arm for hard manual work will be willing to sacrifice strength for mobility. The artisan who has an ankylosed arm in a good position will prefer it to a weak mobile one. The following conditions indicate the type of case where a pseudarthrosis is likely to be satisfactory, and that in which it is best to recommend fixation.

Provided that the flexor and extensor muscles of the joint can act, mobility may be indicated when—

- (a) An ankylosed elbow is fixed in a bad position.
- (b) A short fibrous ankylosis exists with pain.
- (c) The articular ends of the bones can be defined.
- (d) An ankylosis has occurred in each elbow.
- (e) Ankylosis of shoulder or wrist co-exist.

Fixation is usually indicated when—

- (a) The ankylosis is in a good position.
- (b) The muscles governing the elbow are extensively damaged.
- (c) There has been severe comminution with callus.
- (d) The joint is surrounded with scar tissue.
- (e) The opposite arm has been amputated.

Correction of faulty ankylosis of the elbow is best done by an open operation. A posterior incision three or four inches in length is made in the vertical plane, and a subperiosteal osteotomy is performed. There is no necessity to remove a wedge. If the articular bone is comminuted, an osteotomy should be planned through the lower part of the humerus just above the joint. The arm is then fixed for six weeks. In the absence of pronation and supination of the forearm, where it can be shown that there is no ankylosis of the lower radio-ulnar joint, the head of the radius should also be removed and the periosteum should be sewn over the divided end. This operation should not be done at the same time as the osteotomy, otherwise the necessary passive and active movements, so essential to success, cannot be proceeded with. Recurrence

of stiffness occurs sometimes after removal of the head of the radius, and this is usually caused by excessive callus. To minimize this risk, the head of the radius should be removed very freely, and Horsley's wax should be rubbed into the cut end of the bone, or the periosteum should be stitched over the bone, or fascia should be wrapped around it. In addition, the end of the bone should be rubbed smooth.

Excision or Pseudarthrosis of the Elbow Joint.—It will be in the memory of many surgeons that in the days when the usual classical excision of the elbow was practised very excellent results were often obtained. When examined many years afterwards these cases gave evidence of considerable power and stability, and muscular control became much more marked with time. A great number of the successful cases have been those where very free removal of bone has been practised. The incision to be adopted is the posterior one. It should be about four inches in length with its centre opposite the prominent tip of the olecranon. The points upon which stress should be laid are, the preservation of the insertion of the triceps and its expansions into the deep fascia of the forearm over the anconeus; the preservation of the lateral ligaments; the clearing away of detached periosteum; and, where ankylosis is bony, a preliminary section of the bone should be made with an osteotome, or saw, at the level of the joint. The section of the bones should ensure the removal of the greater and lesser sigmoid cavities with the olecranon, and the head of the radius should be removed just above the insertion of the biceps. The section of the humerus should be above the level of the epicondyle on the outer side and through the highest part of the epitrochlea on the inner side. If less is removed, ankylosis is almost certain to result. When the arm is extended there should be an interval between the bones of $1\frac{1}{2}$ in.

If these points are remembered excellent results will follow the operation of excision. The line of approach to the joint is not a matter of real importance, but unless the surgeon has had a considerable experience of excision the posterior vertical incision is more simple than the lateral.

The after-treatment is important. The arm should be kept absolutely fixed at right angles until the stitches are removed, and then very gently flexed to an acute angle once a day for a further period of a fortnight. At the end of that time the wrist is slung by a halter and is lowered by degrees to an angle of 120 deg. of extension, the patient being allowed active movements. At night it is kept flexed to 60 deg.

and released in the morning. This prevents strain of the brachialis anticus and biceps, and should be continued for some weeks.

Certain modifications may be made in the operation. They have been suggested in order to overcome the two cardinal difficulties, namely, recurrence of ankylosis on the one hand, and a weak flail-like joint on the other. Hitherto, the only safeguard against recurrence of ankylosis has been the wide removal of bone, and it is just this step which gives rise to the opposite trouble, namely the formation of a flail-joint. Instead of removing an excessive amount of bone it is better to prevent adhesions of the new bone surfaces by a free transplantation of fat, the fat mass being taken from the patient's buttock and of a generous size, so as fully to fill the space left in the new joint. When this procedure has been adopted the removal of bone need not be so extensive. The olecranon and both epicondyles should be preserved and this may be done in the following way: through the usual posterior incision the lower end of the humerus is exposed and both epicondyles are chiselled off and left attached to the soft parts. This ensures the preservation of the lateral ligaments. The lower end of the humeral shaft is cut off and shaped like a saddle by means of a file, concave from side to side and convex from before backward. The great sigmoid cavity of the ulna is similarly shaped, but is made concave in its long axis and convex in its transverse.

Wrist Joint.—Ankylosis of the wrist joint may be due to one of several causes, and the liability to its occurrence is much increased when two or more of these are present concurrently, as is so often the case with war wounds. The most frequent of these causes has been prolonged fixation of the joint, usually accompanied by septic infection in its neighbourhood. The causes of ankylosis may be tabulated as follows:—

- (a) Prolonged immobilization.
- (b) Contraction of scar.
- (c) Shortening of muscles.
- (d) Bony block due to fracture and dislocation.
- (e) Synostosis due to septic arthritis.

The rigidity is frequently due to an easily avoidable cause, namely, the application of an unsuitable splint. In many cases the surgeon clearly grasps the idea of dorsiflexion of the wrist, but applies a splint to the limb which only succeeds in hyperextending the fingers, whilst allowing the wrist to remain flexed or in the straight position. Following this,

there results a rigidity of the metacarpo-phalangeal range of joints which may require months for its correction, and is due either to the fact that the arm has been slung by the wrist, which becomes palmar-flexed, or else that a straight splint has been applied which has overextended the fingers whilst it palmar-flexed the wrist. In other instances a long dorsiflexion splint has been applied which has slipped upwards, and the fingers have been dorsiflexed instead of the wrist. In order to avoid these troubles, the palmar portion of the long dorsiflexion hand splint should not be straight and flat, as is so general, and it should be provided with a thumb-piece. The proper position of rest for the hand is that which it assumes when it holds a large tumbler, the wrist extended about 45 deg. and the metacarpo-phalangeal and inter-phalangeal joints each flexed to an angle of 25 deg. and the thumb abducted and somewhat rotated on its carpo-metacarpal joint so that its palmar surface looks directly towards the palm. This is the position of maximum utility of the hand, and the one in which all the hand muscles are in a position of relaxation ; fixation in this position will never result in a useless, rigid wooden hand.

If ankylosis of the wrist joint is present in any position, except that of dorsiflexion, then the first thing is to correct this deformity. This may be done gradually on a long, properly shaped dorsiflexion splint, or under an anæsthetic if great force is needed. A short dorsiflexion splint should then be applied, which, while maintaining the wrist in the correct position, leaves the metacarpal and inter-phalangeal joints free. If much force has been needed the splint should be left in position for ten days or a fortnight, the fingers being very gently moved and massaged. Then the splint must be removed daily, the wrist exercised, and the splint readjusted until the deformity shows no tendency to recur.

Stiffness of the wrist due to contraction of the skin or the deeper tissues is treated on the same principle as that adopted where the contraction is due to prolonged immobilization. But the dorsiflexion must be maintained for a considerable period, more especially if the skin is at fault. The scar, by drawing upon healthy skin under tension, becomes gradually so loose and relaxed that recurrence of the deformity does not take place.

Stiffness due to the contraction of tendons, the result of injury to muscle, is very frequent, and it results in a condition often indistinguishable from Volkmann's ischæmic palsy. This condition should be treated as follows.

An assistant passively flexes the wrist to allow the fingers to extend, and each finger is separately strapped to a little gutter splint so that it cannot curl up. A day or two later, or in milder cases at the same sitting, the metacarpophalangeal joints are stretched, and the palm and splinted fingers are bandaged to a flat metal splint—the wrist meanwhile being palmar-flexed. The wrist is now from day to day extended a little and fixed.

This is continued until the wrist is dorsiflexed. The hyper-extension of wrist and fingers is maintained for some time, in obedience to the principles laid down concerning the extension of scars, massage being systematically practised. By this simple procedure the surgeon does much more than any operation would effect. He stretches all the scar tissues in the direct order of their tension. The muscles, infiltrated with fibrous tissue, are really the seat of a diffuse scar, and the effect of continuously stretching them releases the pressure upon the vessels, and in this way the nutrition of the limb is improved.

Bony Block of Wrist due to Fracture and Dislocation.—The cases of fracture and fracture-dislocation in military surgery bear but little resemblance to those of civil life. They are usually accompanied by laceration and comminution, which add to their complexity. Every case of malposition should be corrected. The wrist should never be allowed to remain palmar flexed, and no operation for the excision of bone should be attempted unless there is a reasonable prospect of improved function. If masses of bone or angular splinters interfere with the function of joint or tendon they should be removed. If in an old compound dislocation attempts at dorsiflexion increase the danger of pressure upon soft structures, bone should be removed, and an ankylosis in good position secured. Very rarely indeed is an operation for a pseudarthrosis or excision called for.

Rigidity of the fingers whenever present must be corrected as completely as possible before any operation involving fixation of the wrist is performed, and, if possible, the fingers should be left free to be exercised by active and passive movements during the whole course of treatment.

Bony Ankylosis of the Wrist.—If the wrist joint is in good position it should be allowed to remain so without operation. If the ankylosis is faulty a wedge resection should be performed, and the joint placed in dorsiflexion. Ankylosis of the wrist may occur with or without loss of pronation and

supination. It may be confined to the radio-carpal joint or be combined with the lower radio-ulnar. If synostosis has occurred at the radio-ulnar joint, movements may be regained by removal of a portion of the lower third of the ulna.

Stiff Fingers.—Rigidity of all the joints of the fingers, but especially of the metacarpo-phalangeal range of joints, was one of the most frequent deformities met with in the military hospitals. This rigidity was usually present in all the joints of each of the fingers, but was present to such a degree in the metacarpo-phalangeal range of joints that no flexion could be produced, even with the exertion of considerable pressure. As regards the causation of this rigidity there were several factors which were so frequently present that they might rightly be deemed to be the origin of the deformity.

- (1) Nerve injury, especially of the median or ulnar nerves.
- (2) Prolonged splinting of the hand.
- (3) Septic infection.

An interesting clinical point in regard to this was demonstrated, namely, that after injury of the median or ulnar nerve in the arm, rigidity frequently followed if a splint had been applied to the hand, whilst it very rarely occurred if this splinting of the hand had been omitted.

The treatment of cut or adherent tendons and of adherent scars must follow ordinary principles. It is a wise rule to proceed by gradual stages rather than to attempt full correction at one operation. Thus adherent cutaneous scars should first be dissected out or replaced by new skin. Then adherent or divided tendons should be restored at a second operation. There are two devices which are worth a trial. The one is the replacement of gaps in the extensor tendons by strips of fascia lata. The other is the provision of a new sheath for a damaged or adherent tendon by means of a length of the saphenous vein. It must be admitted, however, that even when the scars have been removed and the tendons are intact the functional result for the stiff fingers is often very disappointing.

Hip Joint.—Fixation of the hip joint due to adhesions of a slight character can be dealt with in the massage department or gymnasium, but there are graver types which for convenience of description may be divided into groups:—

- (a) Fibrous fixation due to prolonged immobilization usually found in connection with fracture of the femur which has become septic.

- (b) Gunshot injury to the femoral neck or trochanter with considerable scarring.
- (c) Painful hips with limited movement, such as are caused by hypertrophic osteo-arthritis.
- (d) Bony ankylosis.

The deformities seen are flexion, adduction, and usually some internal rotation.

Flexion deformity of the hip joint following septic infection should always be treated with the greatest gentleness and care, because rough handling may easily light up latent sepsis and thus cause fatality, and for this reason it is advisable to wait for a long period after the healing of the wound before attempting even a simple forced manipulation.

Deformities due to fibrous fixation, the result of immobilization, can be treated without fear of any reaction in the joint, but as there often is an old fracture of the shaft, the greatest care should be taken not to damage this. If stiffness is not extreme the old fracture should be protected by splints, and the sound thigh bent on to the abdomen to obliterate the lordosis, while the flexed thigh is gradually straightened. If it is found that this cannot be done without great force, the manipulation should cease, for it is very easy to fracture the neck of the femur. The thigh, still being protected by splints, should then be placed upon an abduction frame so as to obliterate the flexion, shortening and adduction. If much adduction of the thigh is present subcutaneous division of the adductors will lead to a much more complete correction of the deformity. If the deformities are fully corrected it will be found that the pubic spines are on the same plane, and that the thigh of the good leg can be placed on the abdomen without causing flexion of the unsound limb. When no pain remains in the hip joint, the application of a Thomas' walking calliper splint will allow the patient to get about freely and will prevent the recurrence of deformity, but if the joint is still tender and painful, continued fixation of the limb must be persisted in until this sign of inflammation has disappeared. If the stiffness does not diminish, but increases on any attempt at movement, it should be dealt with as a case of arthritis, and as soon as the fracture admits of it, the hips should be fixed for walking. At a later date, movements may spontaneously appear, and then surgical treatment will be productive of further improvement.

Where the deformity follows a gunshot injury through the neck of the femur, treatment is attended with grave

responsibility. If the fracture has been septic the bone will remain very soft for months, and it is much better to allow the deformity to remain indefinitely—twelve months or two years—before placing the patient on an abduction frame for gradual straightening. Where fracture of the trochanter alone exists, this precaution is not needed, and the limb can at once be placed on an abduction frame.

Painful hips with limitation of movement have frequently been noticed, but more particularly among elderly men, and have apparently been the result of exposure and perhaps of hard marching, resulting in what may be termed a "traumatic osteo-arthritis." In the young this condition becomes stationary, but in the old it is nearly always progressive, and the X-rays show osteophytic changes as in osteo-arthritis. In both classes the condition is often associated with adhesions which still further limit movement and give rise to pain. In the case of the young, considerable improvement follows careful stretching of adhesions and gentle exercises conducted by a trained gymnast. In the elderly it is advisable to rest the joint and to keep it under restraint during walking. On several occasions operations have been called for because the joints have been exquisitely tender, so that the patient could neither sit nor lie in comfort, and when this has been complicated by stiffness of the opposite hip the condition is deplorable, and urgently requires treatment. Excision of the head of the bone is obviously a very serious operation in men over fifty and is associated with great shock. Recourse may then be had to an operation which was found helpful on many occasions before the war, which does not involve removal of the head, and is described below.

Bony ankylosis of the hip is not very common. A hip which is fixed at a good angle, whether by bony or fibrous but sound ankylosis, should be left alone unless some exceptional reason for interference exists. Such a hip will bear weight without reaction and in many instances men can walk ten miles with ease in spite of this condition.

If the ankylosis is in a bad position this should be corrected by one of the following operations :—

- (a) Transtrochanteric osteotomy.
- (b) Subtrochanteric osteotomy.
- (c) Removal of a wedge.

Transtrochanteric osteotomy gives the most accurate mechanical result. It should be practised in all cases of bony fixation where the femoral neck is not absorbed, and where

there is no marked pathologic displacement. It may be done subcutaneously with a saw or else by an open osteotomy.

Subtrochanteric osteotomy is indicated where it is necessary for the incision to be away from the old seat of mischief, or where the fibrous ankylosis is in process of becoming sound. It is contra-indicated where the flexion is extreme, as the upper end will form a sharp prominence in front.

A wedge operation is indicated where the neck and head of the femur are absorbed, also in pathologic dislocations and where a mass of bone has to be divided, but tenotomy of the adductors is necessary in order to complete the correction of the deformity.

After any operation and before fixing the patient in an abduction frame it is often advisable to apply a pulley to the limb so as to bring the pelvis down. The degree of abduction at which the limb should be fixed depends upon the amount of shortening. The greater the shortening, the greater should be the abduction. When an abducted femur is united by ankylosis to the pelvis it is clear that the limb can only be adducted at the cost of depressing the pelvis on the injured side, and in this way one or two inches of shortening may be compensated for.

The Mobilization of Ankylosed Hips.—Apart from the exceptional case where a patient insists on having movement, which he regards as more important than stability, mobilizing operations should only be performed for :—

- (a) Cases of double ankylosis.
- (b) Cases of unsound ankylosis with adduction.

Even in a case of unsound ankylosis it should be explained to the patient that a sound ankylosis could be assured him by operation, which would include a correction of his deformity and relieve him of all pain.

In cases of double ankylosis operation is obviously imperative, and if the ankylosis is bony with the usual deformities, one joint should be treated by osteotomy and the other by creating a pseudarthrosis. The shorter limb should remain ankylosed, as pseudarthrosis or an excision is followed by some shortening. The operations from which a choice can be made are :—

- (1) Excision of the head.
- (2) Pseudarthrosis to reconstruct the joint.
- (3) Pseudarthrosis without removing the femoral head.

The choice between an arthroplasty and an excision is often difficult. An excision should be reserved for cases where disease is present ; where there has been much comminution ;

where the contour of the bones forming the joint is lost ; and where pathologic displacement has occurred.

The posterior approach is to be preferred to the anterior, and either the longitudinal or the Kocher incision can be used.

If arthroplasty is selected Murphy's operation as described by Binnie, but with a goblet incision, the stem of the goblet passing vertically over the trochanter, is sound and practical.

Pseudarthrosis of the hip joint without disarticulation of the head of the femur is reserved for elderly men and those patients who have extremely sensitive hips, who cannot stand the shock of disarticulation. It is also suitable for cases where a mass of bone has formed around the joint. It often results in an excellent mobile hip, but a calliper has to be worn for some months. It is an operation devised to avoid the friction which is the cause of the acute pain in these cases. The operation consists in removing a slice of the great trochanter, chiselling through the neck, and screwing the separated portion of the trochanter to the proximal end of the neck in order to avoid union of the fragments. It is performed as follows:—A longitudinal incision is made about six inches in length from the upper border of the trochanter just below the insertion of the gluteal muscles. A slice of the trochanter from this point to its junction with the neck above is sawn off or else separated by a very wide osteotome and retracted upward. The joint capsule is now opened and the head separated from the neck with an osteotome. Extension is next put on the femur, and the trochanter with its muscles attached is screwed on to the head of the femur, which remains in the acetabulum. Deep and superficial sutures complete the operation. In the case of a tender joint it may be necessary to remove a portion of the neck. In the case of an ankylosed joint the neck should be divided close to the acetabulum.

After all these operations the limb should be kept at rest for about nine days, and then very gentle passive movements should be practised. A calliper splint should be worn in order to permit of walking without allowing strain on the joint.

Stiff and Ankylosed Knees.—Fractures about and into the knee joint sometimes present a most obstinate rigidity. The rigidity is so marked that very forcible efforts at flexion under anæsthesia utterly fail to gain even a few degrees. Fortunately, such cases will sometimes yield to the influence of gravity and gradual pressure. In certain cases a limited flexion can be produced under anæsthesia, but any attempt at increasing this is so resisted by firm tissue that the surgeon has to desist, as further

pressure would result in rupture of the patella or its ligament, or of the insertion of the quadriceps into its upper border. If such a limb is fixed by splint or plaster in the newly gained position and kept fixed for a week or so, a further gain can be secured under another anæsthesia. This can be repeated until a fair range of movement is acquired. The fixation of resisting tissue under strain renders such tissue less obstructive.

When strong periarticular adhesions are thus stretched a certain transient degree of stiffness will occur, but after a short course of massage and voluntary effort this will disappear. The advantage of gradual stretching over rapid tearing is that hæmorrhage is absent and the reaction is slight and temporary.

In the treatment of injuries to the knee such as occurred in the war forcible manipulation has but a very limited field of application, and should be confined to the lighter types of so-called periarticular adhesions. In the more rigid type of case the aim should be to obtain only a few degrees of movement in successive stages. The types of stiffness of the knee requiring surgical intervention are: 1. Periarticular adhesions. 2. Muscular adhesions to the bone. 3. Scarring and shortening of capsule. 4. Intra-articular adhesions due to arthritis or fracture. 5. Fixed patella. 6. Bony ankylosis of femur and tibia.

The treatment of periarticular adhesions has been noted above.

Muscular adhesions interfering with flexion are generally associated with the quadriceps. If this muscle is firmly bound down the rigidity of the knee is very marked. These are the cases where surgeons point out that after forcing the knee they have gained a slight degree of movement. If the knee is examined, however, it will be found that they have either stretched the patellar ligament or even ruptured it. These cases should never be subjected to forcible movement, for they have often been complicated by a compound fracture, or suppuration in muscle-sheaths, or osteomyelitis. The operative treatment for this condition is to detach the muscle from its adhesions and to place a living flap of fat and fascia between it and the bone. The knee should be kept flexed during healing and the muscle subjected to faradic stimulation. Certain cases in which there has been loss of muscle structure, resulting in shortening, may require operative elongation of the quadriceps tendon.

In cases of shortening of the capsule the X-ray picture may exhibit a perfectly normal joint. The patella is free. There is no undue tension of the ligamentum patellæ, the

quadriceps is not adherent, and yet the knee is firmly rigid. With these symptoms a diagnosis of contracted capsule may safely be made. This condition should be treated first of all on the lines laid down in connection with severe periarticular adhesions, and if the rigidity still persists the following operative interference may be required.

A curved incision should be made from the femoral attachment of the internal lateral ligament to the tubercle of the patella. The capsule is exposed. This is then incised by a curved incision extending across the anterior aspect of the ligament. The patellar tendon need not be divided if it does not obstruct; if it does, it can be elongated by a **Z** incision. The operation is simple, should involve no risk, and has given excellent results.

Intra-articular adhesions are treated by gradual flexion under careful observation. If signs of severe inflammatory reaction should appear treatment by this method should cease. A little pain and some effusion need not interfere with the stretching. Severe pain with rise of temperature is an indication of trouble.

The patella is sometimes bound down by adhesions to the femur. If the adhesions are slight they may be sometimes broken down by manipulation and exercise. If not, the bones may be freed by operation. If the attachment is bony, the bones may be separated by a chisel and a flap of fascia introduced. If the bony attachment is extensive and rugged, the bones should be made smooth and level. Horsley's wax can be rubbed into the femoral erosion and fascia may be laid upon the surface of the patella.

Bony Ankylosis of the Knee Joint.—If ankylosis is complete and the bones are in a good position, no surgical interference is needed. Arthroplasty of the knee has no place in war surgery. Cases have been seen where a gunshot wound, not complicated by sepsis, has caused a very limited ankylosis and these can be operated upon with advantage if the joint is otherwise healthy. It is best not to introduce flaps of tissue but, after chiselling through the obstruction, to excavate the attachments, making them saucer-shape, rubbing in Horsley's wax and keeping the knee flexed or in any position whereby the raw surfaces are kept apart.

Ankylosis in bad position may be due to (a) flexion; (b) lateral deviation; or (c) genu recurvatum.

If the knee is flexed and sound and painless, with no more than 30 deg. of flexion, it is best to leave it alone. If the

flexion exceeds that, an operation is advisable. A wedge of bone should be removed from the front of the knee, so that when the bones are subsequently wedged together firmly the knee remains at an angle of about 15 deg. Supracondylar osteotomy, unless planned to avoid recrudescence of sepsis, is inadvisable, as the result is never so artistic, more especially if the flexion is marked.

Lateral deviation should be treated as in the case of genu valgum by a supracondylar osteotomy, care being taken to place the upper fragment well forward. It is not necessary to remove a wedge. After excision and osteotomy a calliper splint should be worn for at least three months.

The Ankle Joint.—Stiffness of the ankle may be due to :
1. Periarticular adhesions. 2. Fracture dislocation of the astragalus. 3. Malunited Pott's fracture. 4. Chronic septic arthritis. 5. Bony ankylosis.

Periarticular adhesions are treated on the same lines as those of other joints. Many of the disabilities of the anterior portion of the foot are due to stiffness of the ankle, often caused by nothing worse than adhesions, and are easily rectified by manipulation and massage.

In the case of old fractures and fracture dislocation if the fracture was not a compound one and the displacement is not marked the disability will not call for a cutting operation. A thorough manipulation under anæsthesia, followed by massage and exercise, is alone required. The full range of movement after this injury is often unobtainable, more especially if the astragalus has been crushed into the os calcis. If either the anterior or posterior half has been displaced it should be removed by operation. If both are displaced, one half forward and the other toward the tendo Achillis, the astragalus should be removed completely. If the astragalus is removed, care should be taken that the foot is not displaced forward. The os calcis should not be allowed to slip out of the tibio-fibular socket, or a varus deformity will occur. After the operation the foot should be kept at complete rest for a fortnight before commencing movements.

Malunited Pott's fracture, either simple or compound, will sometimes result in a firm fixation of the ankle, and operation must be directed to correct this faulty alignment. The astragalus in such a case often is separated from the internal malleolus. The correction of the deformity requires an operation, and the simplest one consists of an osteotomy of the fibula at the point of fracture, and the removal of a small

wedge including the line of fracture in the tibia. By means of a Thomas' wrench the eversion is corrected, the complete operation being effected in a very few minutes. If the fracture is a compound one, and has resulted in a septic arthritis, removal of the astragalus or cuneiform exsection is indicated.

In chronic septic arthritis, which has resulted in a painful condition of the joint with limited movement, arthrodesis is best unless there is much destruction of the astragalus. This operation is done by making a vertical incision over the front of the joint, and then with a curved chisel stripping the joint of its cartilage, including a thickness of about $\frac{1}{4}$ in. of bone. Osteotomy of the malleoli will then enable the bared edges to be brought into close apposition to the astragalus.

Bony ankylosis should only be interfered with in order to place the foot in a good position, and the best position of the foot for an ankylosed ankle is at an angle slightly more dorsiflexed than a right angle, as this allows of a more easy gait than when it is at a right angle.

Flail Joints.

A flail joint is for practical purposes almost useless, because although the muscles may be present the bone ends lack apposition, and therefore there is no fulcrum on which they can act. Flail joints arise from destruction of the joint ends by gunshot injuries or from the extensive operations required for the treatment of these conditions.

In order to prevent the occurrence of a flail joint, three principles should be observed:—

- (1) The original operation should be as conservative as possible, those pieces of bone only being removed which are severed from all their connections.
- (2) Long-continued extension should be avoided. If a comminuted fracture of the elbow joint, which has been treated by resection, has been put up in a straight Thomas' splint and extension maintained in this position for several months, such treatment will certainly produce a flail joint.
- (3) After a conservative resection has been performed the limb should be so placed as to bring the bone ends into near contact, and it should be retained in this position for a prolonged period. The position chosen for retention should be that which will give the best possible use of the limb if stiffness results.

Treatment of flail joints may be considered under three headings :—(1) Removal of dead bone and scar ; (2) Immobilization by splint or plaster ; (3) Operation.

In many cases undue mobility of the broken bones is kept up by the presence of dead bone and scar tissue. Existing sinuses should be freely opened and all dead bone removed, and as much scar tissue dissected away as is possible. At the conclusion of this operation the limb should be put up in the best position and immobilized until healing has taken place.

In the majority of cases a very great improvement of function in the loose joint will take place if the limb is forced into such a position as will shorten the fibrous tissue between the bone ends. The bones should be forced into as close a position as possible, and the limb encased in plaster of Paris for three months. During this time all the scar tissue between the bones undergoes the natural process of contraction, and in this way will tend to form a fairly good imitation of the natural ligaments of the joint.

Two types of operation are possible for flail joints. In the first an attempt is made to preserve the mobility and merely correct the instability of the joint. In the second the joint, as such, is abandoned, and the bones are fixed together so as to produce ankylosis. It is hardly possible to indicate in general terms the rules which should guide the selection between these two operations. Usually an attempt is made to retain the movements of the joint in the first place, but if this has still left a weak limb the second type of operation is resorted to. In the joints of the upper limb mobility is often more desired than fixation, whereas in those of the lower limb stability is of the first importance.

Flail Shoulder.—When once the shoulder has become flail it is a matter of considerable difficulty to restore the muscles to a sufficient tone to produce a useful joint, and from a theoretical standpoint the shoulder is a joint in which the flail action is the least objectionable. In the first place an attempt should always be made by keeping the arm in an abducted position for several months to secure the recovery of the shoulder muscles. If a prolonged trial of this method still leaves an arm which cannot be raised from the side by the patient's own effort, it is much better to proceed at once to an operation for arthrodesis. The success of this operation depends on creating a firm bony union between the humerus and scapula,

and also upon the mobility of the latter. If the scapula is fixed, the operation is worse than useless, for then the patient will have an abducted arm which he cannot lower.

Flail Elbow.—For this, as in other cases of loose joints, there are two methods of treatment—the non-operative and the operative—and it is wise to do the utmost possible by the former before embarking upon the latter.

Non-operative treatment consists in the measures which have been described, and it is often possible to remove a very large amount of scar tissue from between the bone ends, the forearm then being put up at an angle of 60 deg. of flexion, and retained there for several months. A word of caution, however, is necessary. If the elbow is put up in a flexed position in plaster of Paris which extends up to the level of the axilla only, the forearm together with the plaster of Paris will tend to slip downwards by the action of gravity, and thus quite defeat the object of the treatment. Therefore effective immobilization of a flail elbow-joint will necessitate the provision of some method of holding the weight of the forearm. This may be done by the use of an abduction splint or else by bringing bands up from the elbow splint over the shoulder-cap and under the opposite armpit.

Before deciding to resort to an operation for the fixation of a loose elbow joint it is always advisable to try fitting the patient with a hinged elbow splint provided with an attachment to the shoulder-cap, so as to support the weight of the forearm, and, if it is very important to have a movable elbow, it is worth while persisting in this treatment for at least twelve months before abandoning the patient to a stiff arm. During the whole of this time every possible means should be taken to improve the strength and tone of the muscles, particularly the flexors, so that the patient may regain control over his limb.

The operation of arthrodesis, or fixation of the elbow-joint, is a simple one in theory, but apt to give very disappointing results. The frequent failure to fix the bones is due principally to the fact that the arm is liable to hang by the side, so that gravity pulls the joint surfaces apart, and also to the poor vitality of the bone ends. One or two methods may be adopted to produce bony fixation of the elbow. In the first, the humerus is definitely wedged between the upper ends of the radius and ulna, and there fixed by a transverse bolt and nut or else by kangaroo tendon, the adjacent surfaces of the bone being bared so as to give close contact. In the other type of operation the ends of all three bones are split,

and divided in such a manner as to produce a large area of raw bone surface for fixation.

Flail Hip.—In the ordinary sense of the word, this condition is very rare as the result of gunshot injuries, but some degree of it may result when the head and neck of the femur have been lost. In these circumstances it is usually sufficient to correct the adduction which is generally present by the division of the adductor muscles, the limb being put up for some time in full abduction. If a considerable amount of the bone is lost, so that no weight can be borne upon the limb, the patient should be fitted with a jointed calliper splint, by means of which he may be able to walk with comparative ease.

Flail Knee Joint.—The truly flail knee is always the result of extensive loss of bone with severance of the lateral and crucial ligaments, and the only possible treatment for such a condition is excision of the joint. In order to secure a firm and rapid bony union between the tibia and the femur in a case of long standing, the ends of both bones may be freely cut, drilled or chiselled, so as to provide a number of bone chips from which new bone can be built up.

UNUNITED FRACTURES.

The principal causes of the non-union of fractures caused by missiles in the war were :—

- (1) Primary loss of substance—56 per cent.
- (2) Displacement with intervention of soft parts—35 per cent.
- (3) Necrosis, or secondary loss of substance—5 per cent.
- (4) Eburnation or sclerosis—4 per cent.

In a certain number of cases a portion of one of the long bones has been blown away, but in the majority of cases of non-union there has been a comminuted fracture, the fragments of which have been too freely removed as a part of the early surgical treatment. Such excessive removal of bone frequently leads to an ununited fracture, unless the bone concerned is shortened by the apposition of the main fragments. The radius, ulna and humerus are the three bones which most often exhibit non-union from loss of substance, and it is not uncommon in the case of the tibia. The femur is rarely the seat of an ununited fracture due to this cause.

In many of the cases non-union is due to great displacement of the main fragments. It is best seen at the upper portion of the femur, and less commonly in the shaft or lower end of the same bone. In the most typical condition, namely, that

of the upper end of the femur, the upper fragment is tilted forwards and outwards, whilst the main shaft of the bone lies behind it with a large mass of muscular tissue interposed between the broken ends. This type of non-union can only result from a failure to put up the fracture with efficient extension and in proper alignment.

The other causes of non-union of fractures are of much less importance. Amongst them must be noticed secondary loss of substance, due to septic necrosis and the sclerosis of the bones. This sometimes follows unsuccessful efforts to unite the bone by plates and screws.

Varieties and Natural Course of Ununited Fractures.

There are three principal varieties of ununited fractures which are liable to follow gunshot wounds.

(1) *Fibrous Union without Loss of Substance.*—In this condition the bone ends are usually thickened and more dense than normal, their vascular channels being filled with new bone. The bone ends are united by a dense bond of white fibrous tissue permitting a certain amount of movement which is usually of a painful character.

(2) *Pseudarthrosis.*—In this condition a false capsule unites the two ends of the bone, and glairy fluid like synovia fills the cavity between the adjacent fractured surfaces. A considerable amount of movement is thus permitted, and such unnatural mobility greatly weakens the limb.

(3) *A Gap Fracture.*—In this type there has been a considerable loss of substance, and the main fragments of the bone have been held apart either by gravity, as in the case of the humerus, or by the presence of an intact companion bone as in the forearm or lower leg. The ends of the bone which are adjacent to the gap become very much atrophied, being conical or irregular in shape and of very frail texture. This atrophy extends some way up the shaft, and consists in a disappearance of the dense bone round the marrow cavity. In this way the bone fragments become reduced to a thin shell of hard matter filled with fat. It is important to bear in mind this fragile character of the bones when any operative reconstruction is contemplated.

The natural course of all these varieties of ununited fracture is to remain without bony union for an indefinite period. A flail-like false joint may be formed, or, what is more common, a weak, unstable and painful fibrous union. Improvement may be expected in such a limb if some external apparatus

can be applied which will enable the muscles to exercise their natural action upon the joints, but however much improvement in the general nutrition of the limb may take place actual union of the bone will not occur.

Non-Operative Methods of Treatment.

Certain general physical remedies, such as passive congestion, heavy massage, hammering the bone ends and rubbing them together, are to be regarded as means of hastening the union in an indolent fracture rather than methods of curing non-union when it has been established. When the bone ends are separated by a definite gap, by a false joint or by a dense mass of scar tissue no external manipulation can bring about their union. If the case is unfavourable for operation, owing to local or general conditions, then the limb should be carefully fitted with a plastic splint moulded on a cast and provided with suitable joints, opposite to the articulations. In other words, an attempt should be made to substitute an exo-skeleton for the missing endo-skeleton.

Operative Methods of Treatment.

In the case of gunshot fractures it is absolutely essential to wait for a long period of time to allow of the subsidence of latent sepsis before any attempt is made for a reconstruction operation. During this period of waiting cutaneous scars must be replaced by thick and healthy skin grafts, deep scar tissue must be thoroughly excised, and the muscles, nerves and joints must be maintained as far as possible in a condition of functional activity.

Refreshment of Bone Ends.—In some cases of fibrous union, where the bone ends lie separated only by a little fibrous tissue, it is a good plan to try to make union possible by excision of the scar tissue from between the bone ends, at the same time making a raw surface in each bone by the saw or by multiple drill holes. If the bone is reasonably healthy, union will take place by natural callus production.

Step-cut Operation.—Usually the ends of the bone have become so indolent and atrophic that they require free removal in order to bring healthy bone surfaces into contact. This is best carried out by the step-cut operation (Fig. 1). Each fragment is brought into the wound, its end cut off and half its thickness removed for a distance of one inch. The other fragment is treated in a similar manner, the two ends are

brought together and accurately fitted and then fixed by perforating bolts, screws or wire.

Intra-medullary Pegs.—In non-union which has been due to mere displacement of the fragments without much change in the bones, the use of an intra-medullary bone peg is by far the

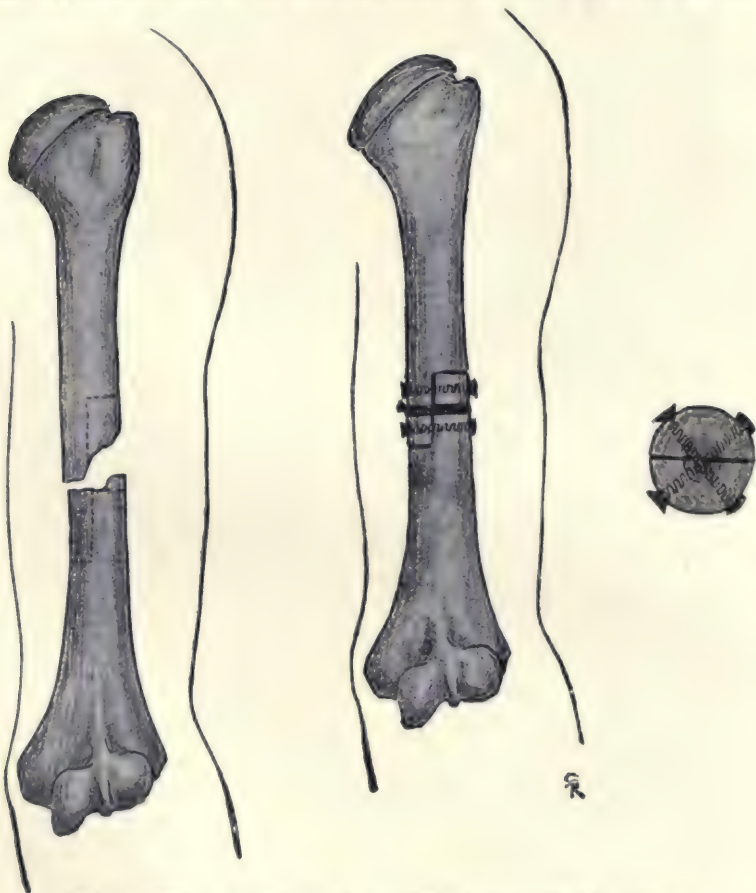


Fig. 1.—Diagram of step-cut operation for ununited humerus.

simplest and most efficient method of treatment. Moreover, the insertion of an internal bone strut, in addition to the other measures used in the step-cut operation, is of great value in strengthening the weakened bone.

Plating.—This is a very unsatisfactory method of treating ununited fractures. By itself it does nothing for the removal of indolent bone tissue, neither does it in any way promote,

and may indeed materially hinder the laying down of new bone. The addition of a plate is certainly sometimes of value if it is simply used as an internal splint to steady a fracture which



Fig. 2A.—Radius and ulna of case eight months after plating, showing non-union of fracture and pulling out of screws.

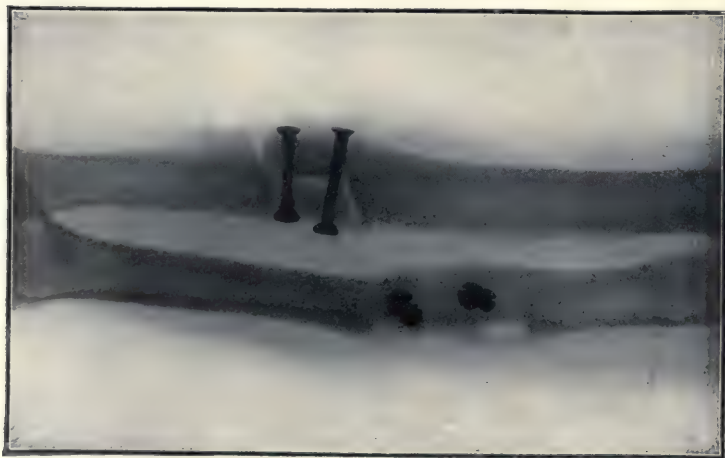


Fig. 2B.—Same case three months after double step-cut operation.

has been step-cut or grafted, but it is only a subsidiary agent and usually can be dispensed with. A very emphatic protest should be made against the common method of attaching plates

and screws to any ununited fracture. The only result of this practice is to bring about further damage to the bones and to produce disappointment in the mind of the patient.

Bone Grafting.—Prior to the war, bone grafting had been used only in rare and exceptional conditions, *e.g.*, those cases where the whole diaphysis had been lost by osteomyelitis or

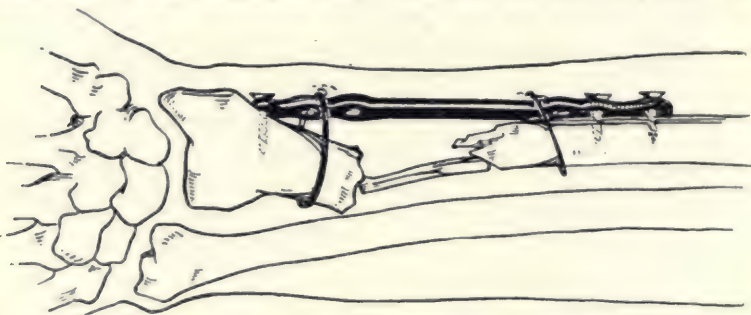


Fig. 3.—Gap fracture of radius. Small inadequate graft with plate.

where a benign tumour had been excised from the shaft of one of the long bones. Many experimental observations had been made but none of these reproduced the conditions of septic gunshot fractures. The same remark applies to the plan of treating simple, closed fractures by means of a "sliding graft" cut from the bone itself.

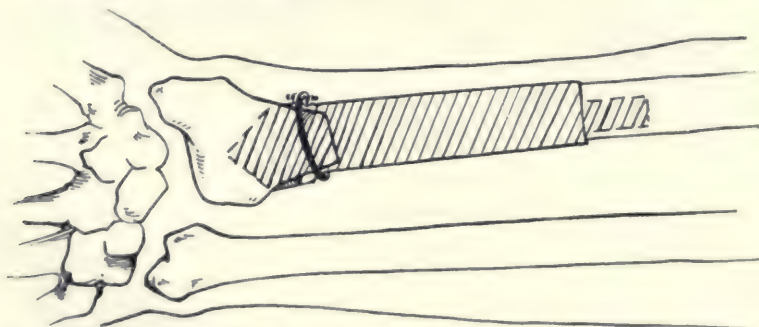


Fig. 4.—Same case treated by an adequate graft which also acts as splint.

In the early stages of the war, therefore, there were no generally accepted principles as a guide in this matter. The following plans were tried and modified in various ways:—

- (a) The sliding graft.
- (b) Small grafts without fixation.
- (c) Grafts attached by wires or sutures.
- (d) Osteo-periosteal grafts.

The Sliding Graft.—In this method two parallel cuts are made down the side of both fragments, one being cut for twice the length of the other. The pieces of bone between the cuts are removed and exchanged, so that the long piece bridges over the gap and rests in the groove of each fragment. This method is inapplicable to the typical gap-fracture resulting from gunshot injury. The bridge of bone is small and quite inadequate to correct or to hold any deformity. Further, both the graft and its bed consist largely of devitalized bone which can produce no new tissue.



Fig. 5.—Failure of sliding graft applied to gap fracture of the radius.

Small Grafts without Fixation.—This is a very attractive method because of its simplicity. The area of the fracture is exposed, the scar tissue removed and the ends of the bone refreshed. Into this gap one or more fragments of bone taken from the patient's own tibia, ribs or ilium, are inserted and held in place by merely sewing over them a tube of soft parts. But this method is very rarely successful in reproducing the shaft of a long bone in an adult. At the best it produces an osteofibrous union between the bone ends which is functionally little better than an ununited fracture. Possibly this method may be used in conjunction with more massive grafts, the small pieces of bone being placed round the junction between the main graft and its bed, so as to help in the formation of callus.

Grafts attached by Wire or other Sutures.—In this method a long trough is cut in the fragments of the broken bone and in this trough is laid a piece of bone cut from the tibia. It is secured in place by encircling sutures of tendon or wire or by metal pins or screws. This method has given a large proportion of successes but it is not so precise or secure as that described below. If fixation is made by animal sutures, such as catgut or kangaroo tendon, the softening of this will lead to early

displacement. If wire is used or metal screws, then it is a common occurrence for irritation to be caused, and this leading to sinus formation requires the removal of foreign bodies.



Fig. 6A.—Fractured forearm bones. There is mal-union of the ulna and non-union of the radius.



Fig. 6B.—The same bones after operation. The ulna has been rectified by a step-cut operation and the radius united by a long tibial graft, both fixations being effected by split-pins. Complete success.

Osteo-periosteal Grafts.—In this method a thin shell of bone is taken from the front of the tibia with its overlying periosteum. The graft is attached by suturing its periosteum to that of the fragments. This method is open to the objection that the graft cannot act as a strut or correct a deformity. Undoubtedly however such a graft can act as the nucleus of new bone

formation, and this method should therefore be reserved for such cases as those where no gap or deformity exists, but where the bone ends are merely atrophic or indolent.

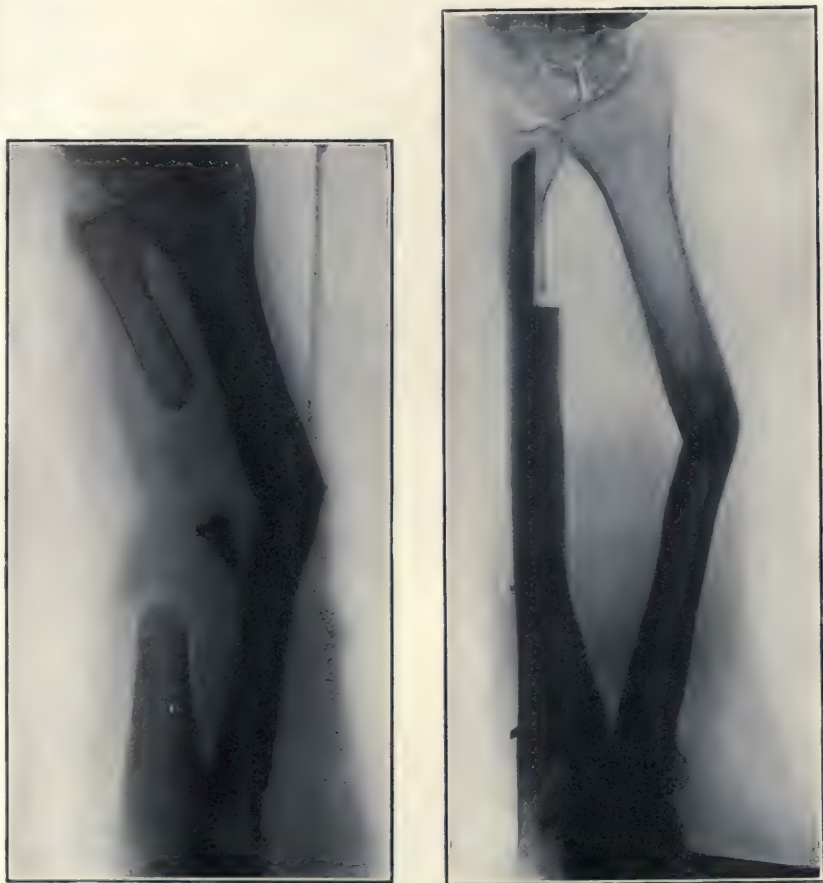


Fig. 7A and 7B.—Forearm bones showing mal-union of the radius and a large gap in the ulna.

Technique of Bone Grafting.

The technique of those methods which experience has shown to be the most successful in bone grafting for gunshot fractures is as follows :—

The Bones of the Forearm.—The technique applies for the most part to the radius. A loss of continuity in the ulna

produces so little functional change, that it is questionable whether a grafting operation is justifiable for this defect. If, however, the ulna has to be repaired, the steps of the operation are similar to those undertaken for the radius. There are two operations which have been suggested for a gap-fracture of one of the bones of the forearm when the other is intact, as alternatives to a tibial graft. If there is, for example, an inch gap in the radius, it has been suggested that the ulna should be shortened by rather more than an inch and united by some kind of "step-cut" operation. There is really only one condition which justifies this procedure, and that is the loss of the flexor or extensor tendons at the site of fracture. In these circumstances shortening the forearm will enable a reconstruction of the tendons to be made. If this operation is to succeed, the shortening of the ulna must be carried out to such an extent as to allow of a free removal of the indolent ends of the radius, because, if the latter are merely brought into apposition without refreshment, non-union will persist. The other operation which has been suggested is the removal of a segment from the ulna and the implantation of this segment into the gap of the radius. This is a much more difficult operation than the use of the tibial graft described below, and it is subject to the great disadvantage that the firm splint provided by the intact ulna is lost.

After trying various types of graft fixed to the surface of the fragments, with a varying degree of success, Hey Groves adopted the use of a graft shaped like a cricket bail, cut from the crest of the patient's own tibia, and this has given such successful results that he now uses it always for mending gap fractures of the forearm bones. The bed of the graft is first prepared by exposing the fractured ends of the bone, freely cutting away the irregular or conical ends, while exposing or baring their surfaces as little as possible. Each fragment is tied down by adhesions of the interosseous membrane is separated from the adjacent bone by blunt dissection. The fragments should then be mobilized freely enough to allow of the end of each being brought well into the wound. This is not merely for convenience at the subsequent operation, but in order to separate the central parts of the shafts of the radius and ulna as widely as possible from one another. When this has been done each fragment is bored by as large a twist drill as can be driven into it easily, *i.e.*, without cutting away anything more than soft marrow or friable bone—the shaft of the radius usually requiring a $\frac{1}{4}$ in. to $\frac{5}{16}$ in. drill for

this purpose. In dealing with a fracture about two inches above the wrist it may be necessary by means of a small chisel to scoop out the cavity of the lower fragment into an oval hole which measures on cross section $\frac{1}{2}$ in. by $\frac{1}{4}$ in. The actual size of the hole does not matter so long as a strong sound shell of bone is left into which the cricket-bail graft can be firmly driven.

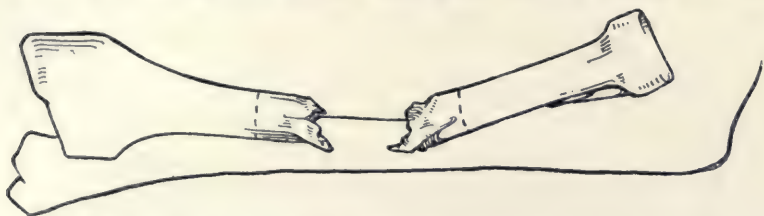


Fig. 8A.—Gap fracture of radius with displacement over ulna.

The depth to which the ends are drilled is not very important ; usually it should be about 1 in. to $1\frac{1}{2}$ in. Careful note is made of the length of the gap left after the removal of the bone ends and of the size to which each marrow cavity has been drilled. The wound is packed and its edges brought together temporarily by towel clips.

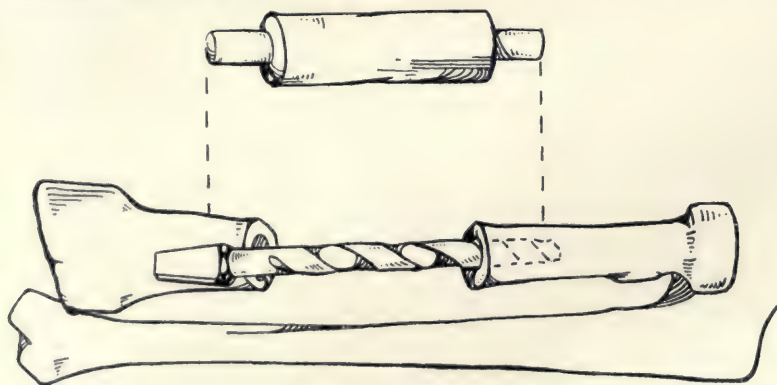


Fig. 8B.—Fragments of radius brought into alignment and both ends drilled by twist drills to receive pegged ends of graft.

The tibia is then exposed by a curved incision, and a length of bone two inches more than the gap to be filled is marked by cutting transversely through the periosteum on its exposed surface. Longitudinal incisions are then made through the periosteum along the extreme borders of this surface of the tibia and the periosteum is turned back from its inner border towards the crest, leaving a strip of bone about half an inch wide

with the periosteum undisturbed. The graft is then cut by four saw cuts with an Albee saw, taking a piece of the crest two inches longer than the gap and of square section half an inch each way. When the graft has been removed the assistant closes the wound in the leg, whilst the surgeon proceeds to shape the graft.

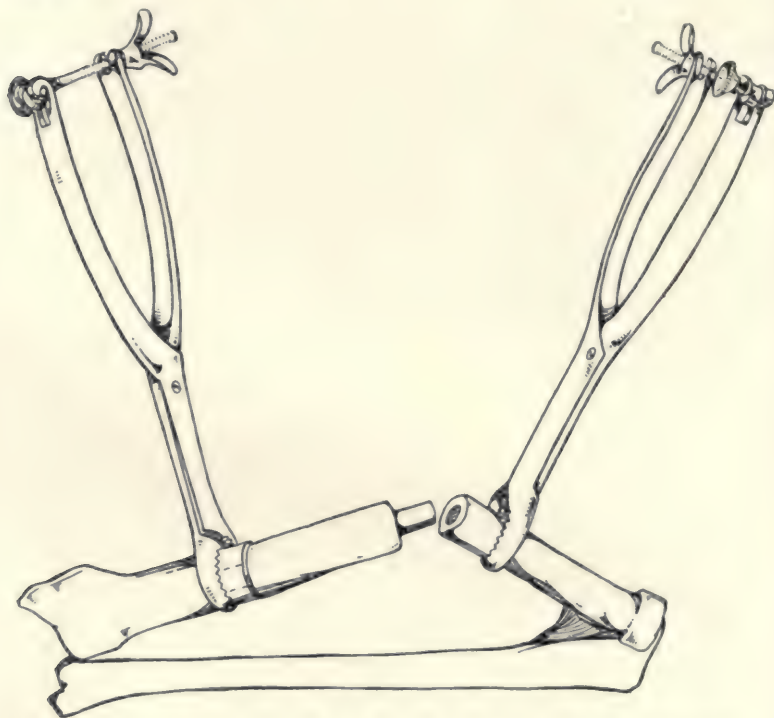


Fig. 9.—Graft being fitted into its bed by eversion of the fragments.

The periosteum is turned back for one inch from each end, the graft is wrapped in a piece of tetra cloth, which leaves the end free for one inch, and placed in a small vice. The bare end is cut down by the Albee saw to something near the size of the hole it has to fit. The angles are then filed and the end is passed through the holes of a reaming plate, these holes corresponding to the size of the drill used. The other end of the graft having been treated in a similar manner there remains a piece of bone consisting of a central stout portion, the length of which corresponds to that of the gap in the radius, and two rounded ends, each one inch long, the thickness of which is

that of the holes in the fragments. To the thick part of the graft a piece of periosteum is attached, with an abundant free margin laterally and at each end.

The wound over the radius is now re-opened and the distal fragment of the fractured bone is grasped by a suitably curved bone-holding forceps and brought out into the wound. The graft is driven into this, and the projecting cuff of periosteum is sewn round the junction between the graft and the radius. Next comes the critical stage of the operation. The easiest and neatest way to insert the proximal peg of the graft is to lever outwards the proximal fragment of radius after cutting the peg to one-third of an inch in length. The graft is then made to engage in the hole of the upper fragment, and

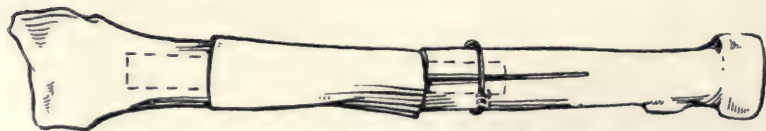


Fig. 10.—Gap fracture of radius grafted from tibia; one end of radius split and wired.

slowly the two are pressed back into alignment. The peg slips into its place with a “click” and for the moment all is well, the periosteal cuff being treated as before. But though this is the neatest way of finishing the operation, it is open to one objection, namely, that the upper peg is so short that it does not serve to keep the graft and upper fragment in alignment and there is a tendency for the radius to “sag” inwards towards the ulna at this point.

The more efficient way of completing the fitting of the graft is to split the proximal fragment of the radius by the motor saw for two inches. The split is then cautiously prised open and the peg-end of the cricket bail is placed in position. The ends of the radius are then tied together with a double turn of fine iron wire. (Figs. 10 and 11).



Fig. 11.—"Cricket bail" graft for gap fracture of the radius, one year after operation.

The Humerus.—The humerus presents one of the most difficult problems for repair, and very special care is required in immobilization, because if this is not attended to and the

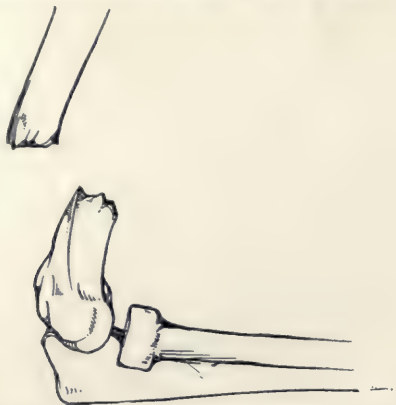


Fig. 12.—Gap fracture lower end of humerus.

arm is left hanging by the side it will drag on the graft. Moreover, the shoulder joint is apt to become very stiff, and each movement of lifting or rotation of the arm puts a great strain

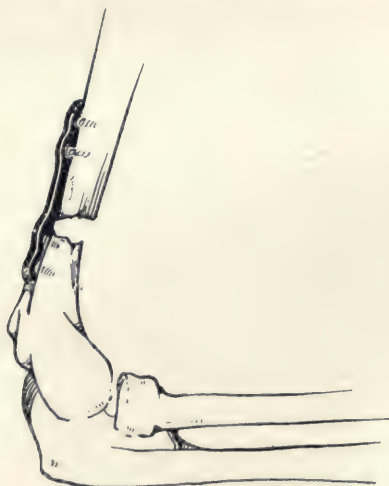


Fig. 13.—Same case as Fig. 12, treated by a plate, without success.

on the graft and its fixation. Three types of graft fixation may be used for the humerus. They may be described as (a) the thrust, (b) the thrust and split, and (c) the two-piece graft.

The thrust graft is especially indicated for cases without much loss of substance, but in which there has been so much absorption atrophy that the ends are too fragile for a "step-cut" union. In principle it consists in nailing the two fragments together by means of a stout intra-medullary nail. Take, for example, a case of a gap fracture at the lower end of the humerus. The region of the fracture is exposed by an incision over the external inter-muscular septum. Each fragment is refreshed and the ends so shaped as to fit snugly against one another when the bone is aligned. Then each end is brought out into the wound and drilled for three inches by a

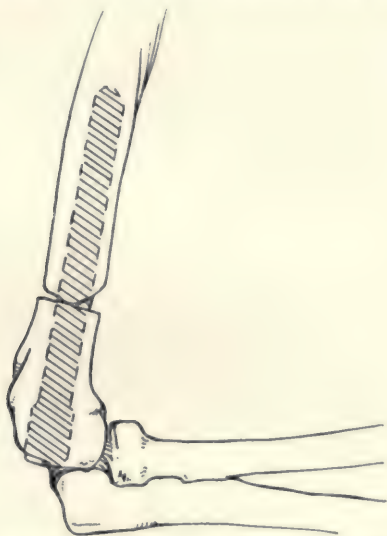


Fig. 14.—Same case as Fig 12, treated by "thrust" graft.

twist drill, usually about $\frac{1}{2}$ -in. in diameter. The distal fragment is drilled last, and, the elbow being acutely flexed, the drill is thrust right through the elbow joint and out through the skin. This external opening is temporarily kept patent by a pair of artery forceps. The graft is now prepared from the tibia, unless a beef bone is being used. In either case the graft is six inches long, rather more than half an inch thick, and roughly cylindrical in shape, with one end slightly pointed. The pointed end of the graft is thrust into the opening at the tip of the elbow, the margins of which are held apart by four pairs of tissue forceps. It is then hammered into place. When its point has reached the gap of the fracture

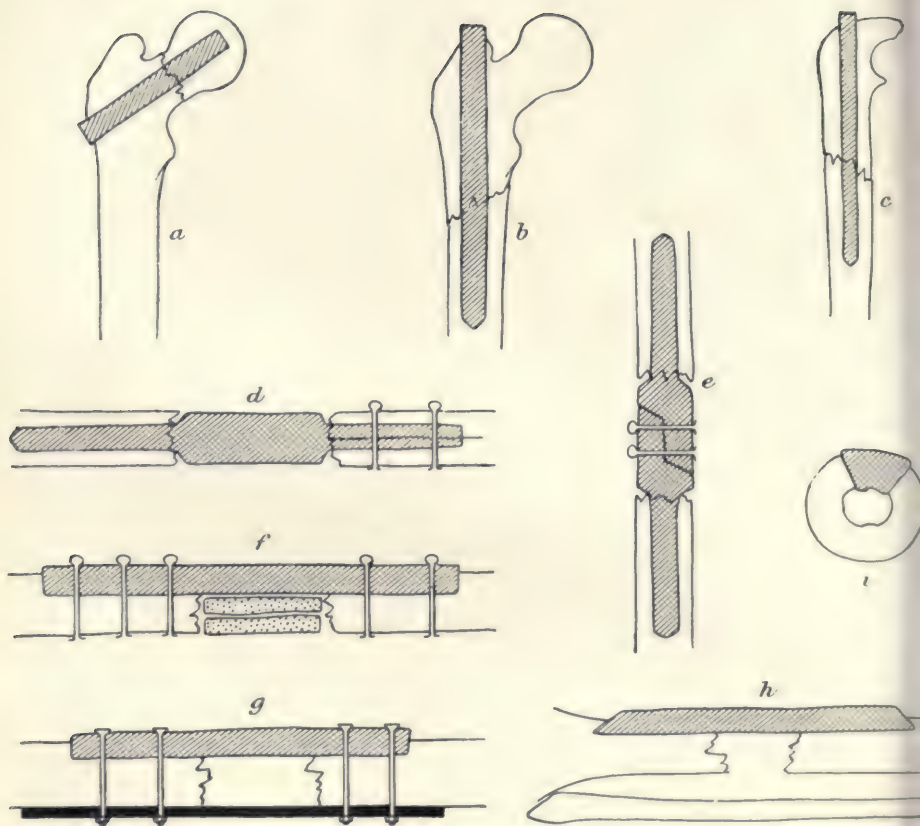


Fig. 15. Showing methods of fixing and fitting a graft: (a) Graft driven into trochanter, neck, and head of femur; (b) Graft driven into medulla of upper third of femur from trochanter; (c) Graft driven into medulla of proximal part of ulna from olecranon; (d) Graft tightly fitted into both fragments of a fracture. At one end the shaft has been split for its reception, and then pinned together; (e) Graft tightly fitted into both fragments of a fracture. The graft has been cut by a fret-saw in a Z manner and pinned together afterwards; (f) Graft fitted as a cortical strut and fixed by pins. The fragments marked by dots have been cut from the shaft and used to fill up the gap between the main ends of the bone; (g) Graft fitted as a cortical strut and bolted to a plate on the opposite side of the bone; (h) Inlay graft fitted and fixed without metallic sutures; (i) Section of the inlay graft, showing its wedge shape.

it is adjusted into the mouth of the narrow cavity of the proximal fragment and the arm is brought into correct alignment, with proper orientation as regards rotation of the forearm upon the arm. The graft is then hammered home until its lower end is clear of the condylar region of the humerus. Extra security against displacement may be gained by a bone nail driven at right angles to each fragment through the graft, but this is not necessary if the fitting of the graft has been sufficiently tight. An exactly similar technique may be employed in dealing with a fracture of the upper end of the shaft. In this case the graft will be driven downwards through the head of the bone in a small incision made between the pectoral and deltoid muscles. The drill inserted into the proximal marrow cavity will find its way through the humeral head, and, the arm being held back, it will present through the capsule of the joint.

The thrust and split graft is suited for cases in which the fracture is in the centre of the shaft. (Fig. 15, *d*.) The general technique is exactly the same as that above described, except that the drill is not made to emerge through one articular end of the bone. The lower fragment is carefully split for three inches. This is done by cutting one wall of the fragment by the motor saw and splitting the deep wall by a chisel. It is very important not to bare this part of the bone by denuding it of its covering of soft parts. The graft is then hammered into the proximal fragment for three inches and laid between the split halves of the distal fragment. These halves are then brought together and fixed by a double turn of soft iron wire.

In both these types of operation the graft is, of course, bare of periosteum, as it has to lie entirely buried in the marrow cavity of the humerus. The two-piece graft (Fig. 15, *e*) is used if there has been such a great loss of substance of the bone that the two ends cannot be brought into apposition. It is then necessary not only to fix the graft into each fragment, but also to bridge the gap in such a way as to give the best chance of new bone growth in this interval. Two grafts are taken; one is firmly driven into each fragment and the two grafts are then united to one another in the gap by bolts or wire. In a gunshot fracture requiring an autogenous graft it is necessary to cut two tibial grafts, or one long one which can be cut into two. Each should have ample periosteum attached to it. The periosteum is turned back from the end driven into the marrow cavity, and is then wrapped round the line of junction

between fragment and graft. The two grafts being united by two bolts or wires, there will be a double thickness of graft in the gap, and this will be entirely covered by periosteum.

The Tibia.—The tibia presents special difficulties of its own. The bone is subcutaneous to a greater extent than any other long bone, and this means that scars of wounds are usually

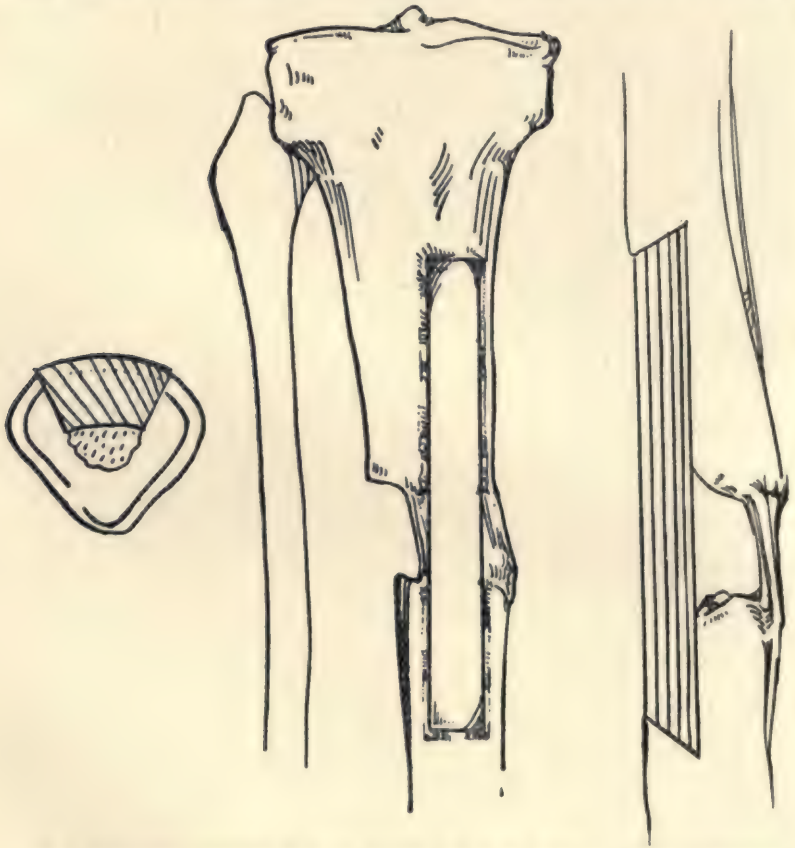


Fig. 16.—Gap fracture of tibia united by inlay graft. Inset diagrams show shape of end cuts of graft in section and side elevation.

adherent to, or immediately over the seat of fracture. Further, in adults the bone is dense and non-vascular, and not suitable for rapid repair. Two separate conditions require consideration, for there may be either an ununited fracture without much loss of substance, or a typical gap fracture. In fracture of the tibia without loss of substance it is more absolutely essential

than anywhere else to replace all scars by healthy skin, so as to leave no cicatricial tissue over the seat of operation. At a suitable period after this has been done the bone is exposed by a long curved flap. Two aluminium templates are used to measure the graft and the bed in which it is to lie. These measure 6 ins. by $\frac{1}{2}$ in. and $6\frac{1}{8}$ ins. by $\frac{3}{16}$ in. respectively, the longer and wider one being used as a guide in cutting the graft, whilst the smaller is for the bed. Each template is provided with four small holes for tacks, the plate being temporarily nailed in place whilst the motor-saw cuts along its edges. The fractured bone being exposed, the periosteum is raised from an area $6\frac{1}{2}$ ins. long in the middle of the anterior surface by a central longitudinal incision and cross-cuts at each end, two flaps being turned aside. The smaller template is fixed in position, and the bone underlying it cut out by four saw cuts. The lateral saw cuts converge towards the axis of the bone, the end cuts undercut the bone, whilst all go deep enough to penetrate the marrow cavity. By means of a chisel the pieces of bone thus marked out are raised from the bed, and a cavity for the graft is left. The graft is cut from the opposite tibia. In this case the periosteum is cut by a rectangular incision half an inch wider and longer than the graft and turned inwards. The periosteum so conserved is protected by the template nailed in position and the graft is cut. If the ends have been properly undercut it will be necessary to remove a wedge-shaped piece of bone at one end in order to free the graft, which is then raised by a chisel with a template still attached. The graft is then placed in its bed. The width of graft and bed ought to correspond exactly, because the wider template used as a gauge for the former allows for the bed being two saw thicknesses wider than the smaller template. The shape of the ends is such that the deep surface of the graft is longer than the superficial. By traction on the foot the bed for the graft is temporarily lengthened, the graft is then hammered down into position, and the two parts of the tibia are forced together so as to lock the graft in position. The edges of the periosteum of the bed are then sewn to those of the graft and the skin flap is closed.

In the case of a gap fracture, if a gap of one or two inches exists in the tibia the choice will lie between shortening the fibula so as to bring the tibial fragments into contact, and filling the gap by a graft. If the gap is more than two inches a graft may be the only alternative to amputation, the choice being between this and a well-fitted boot with side irons. The

best type of graft to use for such a long gap is a homogeneous one taken from a clean, fresh amputation, if such be available. The graft should be prepared with its periosteum in place and a projecting cuff to cover the line of junction between graft and fragments. Two projecting tongues of bone are cut at each end of the graft and fitted into corresponding slots in the fragments.

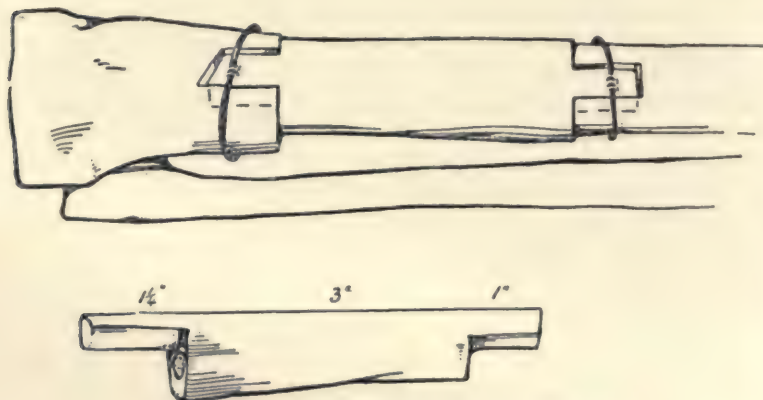


Fig. 17.—Case treated by a whole thickness graft taken from another case (amputation).

The Femur.—In the case of a large gap in the femur, involving more than three inches of shortening of the leg, it is generally wisest to advise amputation, especially if there is much injury to muscles and nerves and if the leg as a whole is much atrophied. Practically every ununited fracture of the femur must be joined with end-to-end apposition of the fragments, as it is not possible in the adult to fill up a gap with a graft sufficiently firm to take the body-weight.

If the thrust intra-medullary peg is used for the shaft of the femur, strong round pegs $\frac{1}{2}$ in., $\frac{9}{16}$ in. and $\frac{5}{8}$ in. thick, and six inches long, should be prepared from beef bone or ivory. It is very difficult to get a solid piece of beef bone more than $\frac{1}{2}$ in. thick, and ivory is better because of its greater strength. The site of the fracture is exposed and the ends are brought out into the wound and refreshed and bored by drills up to $\frac{1}{2}$ in. in diameter. A special long drill is next run up the proximal fragment until the tip of the great trochanter is pierced. A steel rod 12 in. long and $\frac{5}{8}$ in. thick, with a pin at its lower end fitting a hole in the upper end of the peg, is passed up the

proximal fragment until it can be felt through the skin of the buttock, where it is cut down upon and thrust out. The peg is then fitted on to the rod and driven up the femur until only half an inch is left projecting at the site of the fracture. The fragments of the fracture are adjusted and the peg is hammered down into the lower fragment until it lies equally in the two



Fig. 18.—Ununited fracture upper end of femur.

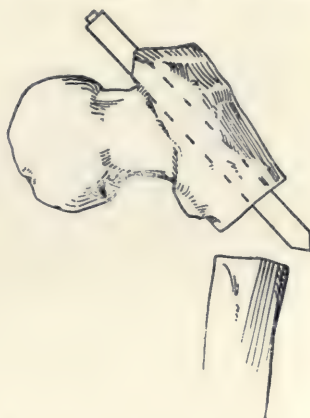


Fig. 19.—Same case with peg inserted into upper fragment.



Fig. 20.—Same case with peg driven down into lower fragment.

fragments. It is very important that the holes drilled in the fragments should be smaller than the size of the peg (a $\frac{1}{2}$ in. hole will suffice for a $\frac{9}{16}$ in. peg), for the rarefied inner layers of the bone readily admit of a peg being forced into a small hole, and it will then be absolutely tight. If the fracture be at the upper end of the femur the peg can be inserted from the tip of the trochanter instead of being passed up the canal of the proximal fragment.

There are two situations in which a bone graft may be easily used for a femoral fracture. One is in the neck and the other in the upper part of the shaft. It is not necessary to give details about the former operation because this has



Fig. 21A.—Femur three months after accident.



Fig. 21B.—Same bone united over a 6-inch by $\frac{1}{2}$ -inch ivory peg.
The wound healed and the fracture united.

been long recognized as the best treatment for non-union of the neck. Only two points may be mentioned. One is that the site of the fracture should always be exposed by an anterior incision such as that used for excision of the hip joint

This is necessary to secure correct orientation of the fragments and proper direction for the graft, and to enable the operator to refresh the line of fracture by the removal of interposing fibrous tissue. The second point is that, whether the graft be beef bone or fresh human tibia, it should be cut roughly half an inch square and driven into a $\frac{1}{2}$ in. round hole. The cancellous tissue permits of this quite readily, and a firmer union results than from the use of a round peg in a round hole.

In using a graft for a fracture of the upper part of the shaft, the operation is similar to that described above, but a graft made from the patient's own tibia is used instead of an ivory peg.

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CHAPTER XIV.

AMPUTATIONS AND ARTIFICIAL LIMBS.

IN 1914 the teaching on the subject of amputations was that of the ordinary text books. Most of the operations were classical; many of them dated from pre-antiseptic days. The teaching of these operations had been modified in accordance with the expectation of securing aseptic healing, but the actual design of the amputation had not been altered, so that, for example, the flaps usually prescribed in text book amputations proved too long when aseptic healing resulted, leaving a flabby end to the stump. Little or no attention was paid to the utility of the stump from the point of view of the fitting of artificial limbs. In fact the number of amputations within the experience of the average surgeon was too small to give him a sufficient experience to guide him either in methods or in results, and it might almost be said that surgeons were entirely without experience of the fitting of artificial limbs.

In pre-antiseptic days amputations were designed with long flaps because a period of granulation was expected during which much retraction took place. If healing was aseptic the retraction was less, and a stump resulted with sound mobile scar but with the skin and soft parts redundant. This redundant tissue is a great embarrassment when the fitting of an artificial limb has to be undertaken. The nature and position of the scars on an amputation stump are important, and the thin adherent scar left after healing by granulation is liable to ulcerate and give way when an artificial limb is worn. In order that it may not give trouble the scar should be linear and mobile, and, if possible, it should be so situated on the stump as to preserve it from pressure or friction. Pain, particularly pain on pressure, must be eliminated. The teaching as to the necessity for shortening the main nerves is old, but has been largely ignored by surgeons inexperienced in amputation work. It is now realized that nerves must not only be shortened, but must be treated in such a manner as to preserve them from adherence to scars or to the bone, and, if possible, steps must be taken to prevent new axis-cylinders growing out from the cut ends of the nerves into the tissue around, where they are liable to pressure. The functional utility of a stump depends

upon the preservation of the full active movement in the remaining joints ; this mechanical principle was at first ignored, so that amputation stumps when they were finally healed were complicated by contracted and deformed joints, and the muscles had frequently been disused for such a period as made it difficult for the patient to use his artificial limb. The importance of this led to steps being taken to preserve joints from contraction, by splinting, massage, etc., and to get the stump into active use at as early a stage as possible by the provision of a temporary artificial limb.

Before the war the methods of performing amputation in the presence of severe sepsis or of extensive lacerated wounds had not been sufficiently studied, and in such cases the immediate mortality from amputation was at first heavy, and led to the consideration of special methods of amputation designed for the preservation of life, and of as much as possible of a badly lacerated or infected limb.

Briefly stated, the lessons of the war have led to :—

- (1) New methods of amputation in the presence of sepsis or severe laceration.
- (2) Methods of treatment of these primary amputations designed to secure rapid healing.
- (3) The determination of the best levels for amputation, and of those methods of cutting flaps and treating nerves, tendons and joints, which leave the best possible stump from the point of view of the subsequent fitting of an artificial limb.

The first of these points was studied at the front, and led to the development of the guillotine amputation and of amputations with flaps cut but turned back. The second was studied at the front, in base hospitals, and particularly at home hospitals, such as the Pavilion Hospital at Brighton and the special military surgical hospitals where amputation cases were congregated. The methods adopted in the later stages of the war led, as a rule, to the final healing of an amputation after a second operation, the total period from primary amputation to final healing being from three weeks to three or four months. In amputations left to granulate and to discharge their own sequestra, or treated by inefficient secondary operations, the period of healing was often a year or more, and it was not unusual to encounter a patient who had been subjected to three or four secondary amputations and many other minor operations. Such a record is a confession of inefficient surgery

The third point was studied chiefly at the limb-fitting hospitals. The method of supplying artificial limbs adopted in 1914 was the following. When a patient who had suffered an amputation was considered ready for an artificial limb, the surgeon of the military hospital in which he happened to be ordered the limb through the hospital dispenser. In some cases the limb-maker attended the hospital and measured the stump, in others the measurements were taken by the dispenser and forwarded to the limb-maker. A limb was then made and was sent to the man, often without any fitting at all. Such a system was unsatisfactory even in peace time, consequently in the summer of 1915 Queen Mary's Auxiliary Hospital at Roehampton was opened in order to provide a special centre at which amputation patients could be collected and have their limbs fitted under the direct supervision of an orthopædic surgeon; subsequently limb-fitting centres were opened in other parts of the country. The experience gained at these centres enabled the men to be fitted with much greater satisfaction, and led also to a knowledge of the amputations which were best from the limb-fitting point of view and to a criticism of the methods of amputation generally adopted. In March 1916, a short memorandum on amputations and amputation stumps was written by the surgeons of Queen Mary's Auxiliary Hospital in which they recorded their opinions as to the best levels of amputation and as to the nature of the ideal amputation stump so far as their experience then went. Subsequent experience has necessitated only a few variations from the recommendations laid down in that memorandum.

Primary Amputations.—In primary amputations in which aseptic healing can be made practically certain, the methods advisable and the levels of amputation recommended are necessarily those which give the most ideal stump from the point of view of limb fitting, but when laceration or sepsis makes aseptic healing improbable, a secondary operation involving an alteration of the level of amputation and of the shape of the stump and position of the scars may be required so that the methods used to obtain an ideal stump cannot be applied to such primary amputations. It was found in the early months of the war that if the flaps of the stump were sutured, sepsis and gas gangrene were liable to occur and to extend with great rapidity leading to a second amputation within a short time or to loss of life, and surgeons soon began to leave the flaps of primary amputations unsutured. The most important new method was that advocated by

French surgeons and by Fitzmaurice Kelly, the description being published in January 1915. This was the guillotine amputation. It consisted in the circular division of all the tissues including the bone at the same level, bleeding points being ligatured, nerves pulled down and cut short and dressings applied direct to the raw surface. The advantages of this method are that it is simple and rapid. Drainage is free and the nutrition of the stump is not in any way impaired. There can be no doubt that before gas gangrene was better understood this amputation saved lives, and although later it was modified by most surgeons in that flaps were cut and turned back, it is possible that no other amputation would have proved as successful in the earlier stages of the war. Moreover, as a guillotine amputation can be performed at a level close down to severely lacerated tissue, it may be doubted whether in many cases the cutting of flaps really saved any greater length of the limb. Both the guillotine amputation and the amputation with flaps turned back must be accepted as advances in the surgery of lacerated and septic wounds which will remain as permanent surgical methods. Kelly in his original description pointed out that the guillotine amputation necessitated appropriate after-treatment and as a rule a secondary operation ; this is true also of the amputation with flaps turned back. The guillotine amputation has been blamed for leaving bad stumps ; but these were due not so much to the amputation as to inefficient or inappropriate after-treatment.

The Treatment of Unhealed Stumps.—When a guillotine amputation or an amputation with the flaps turned back remains aseptic, necrosis of the bone will not occur and secondary suture can be carried out after an interval of days. In most cases, however, such an amputation is, or becomes, infected. Early secondary suture is then impossible because necrosis of the bone is very likely to occur and it is impossible to close the stump whilst adherent dead bone remains. It was soon found that in these amputations a very great retraction of the skin and muscles occurred. It was, in fact, such retraction which in former years had led surgeons to cut the skin flaps of an excessive length. To prevent this complication extension must be kept up upon the skin. The method which has been found most efficient is the use of a splint consisting of a Thomas' ring fitted around the top of the thigh or around the shoulder and carrying side bars which end in a square frame projecting beyond the extremity of the stump

(Fig. 1). Strapping extensions, usually four in number, are fixed to the skin at the sides of the stump and are attached below to a ring which fits inside the square frame; by tying the ring to the frame an extension pull is kept up. The whole of the end of the stump is left exposed so that the dressing can be changed without interfering with the extension upon the skin.

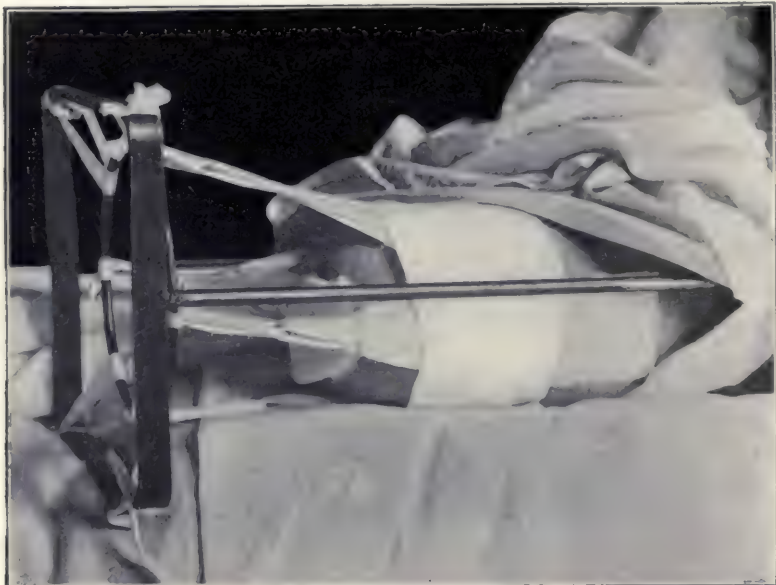


Fig. 1.—Method of applying extension to the flaps of an unclosed amputation stump. A Thomas' ring surrounds the top of the thigh; the lateral bars from this end in a large square metal frame. Four extension straps (in this case of adhesive strapping) are applied to the skin and fastened to a metal ring. The extension is obtained by securing this ring to the square metal frame.

If a guillotine amputation is treated thus and the wound is allowed to granulate without further operative treatment it may heal after any necrosed bone has separated and been discharged, or it may heal only partially and leave either an ulcerated surface or a sinus leading down to other necrosed bone. A stump that has healed by granulation bears a large and adherent scar. In the upper limb this does not seriously interfere with the fitting of an artificial limb, but in the lower limb such a scar is very undesirable and should always be avoided. It is therefore necessary to close in the end of the

stump by a secondary operation, not only because without it the stump may not heal, but also on account of the nature of the scar (Fig. 2). The second operation should be a final one. If it is carried out at the right time and in the right way, it should result in rapid healing, leaving a stump which is in all respects suitable for the application of an artificial limb (Fig. 3).

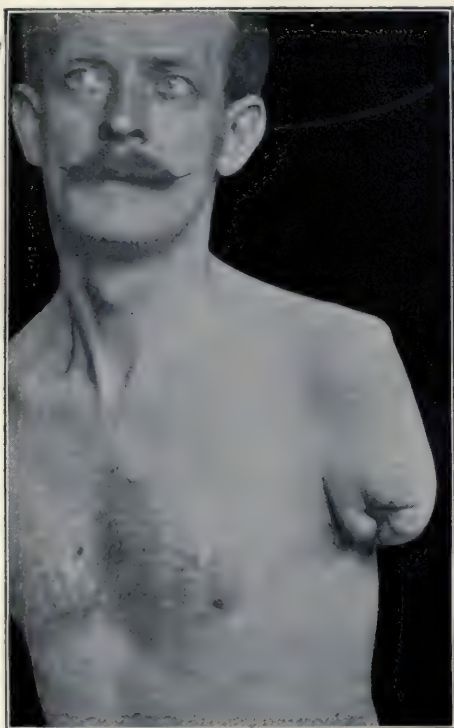


Fig. 2.—The final result of a guillotine amputation of the arm which was treated by the application of extension to the skin. There was a small adherent terminal scar which caused no trouble.

The chief fault has proved to be excessive hurry in re-amputation. Huggins has shown that an important indication that a stump is in a fit condition for re-amputation or closure is the disappearance of œdema. This œdema is an indication that there is some infection in the tissues of the limb away from the end of the stump, and, as these tissues must be divided in the process of re-amputation, the new wound may become

infected, further necrosis result, and the condition present before re-amputation may recur. Other factors that must be borne in mind in considering the possibility of re-amputation are the separation of any necrosed bone or the occurrence of a chronic infective condition in the bone which has to be cut through at the time of operation.

If possible, necrosed bone should be kept in view during the granulating period and an examination should be made from time to time by means of X-rays to determine the state of the bone in the stump. The actual period that must elapse between a primary and secondary amputation depends, to a considerable extent, upon the severity of the infection and the



Fig. 3.—The result of a guillotine amputation of the thigh; there was a large adherent terminal scar which was stretched by the circumferential pull of the artificial limb bucket.

rapidity with which it quietens down. When it is advisable to maintain the original length of the stump as far as this is consistent with safety, the proper time for re-amputation or suture is after a period sufficient to allow of separation of the sequestra and of the disappearance of œdema from the stump. But if the original amputation is at a level which has proved to be a bad one from the point of view of the fitting of an artificial limb, or when an inch or two of bone can be sacrificed without affecting the functional result, much time may be saved by re-amputation as soon as the œdema has disappeared, and such an amputation can be safely carried out provided that the bone is healthy at the point at which it is cut across. When such a re-amputation is undertaken it is unnecessary to sacrifice much of the stump, for all the healthy skin may be retained in the flaps, cutting close up to the margin of the new epithelium.

The skin flaps should then be reflected and the incision deepened on to the bone at the lowest level at which it is healthy, the bone being sawn across at this level. Throughout the operation it must be remembered that the granulating end of the stump and the end of the bone are infected, and these must not be touched with any instrument or swab which is used in the freshly cut tissues. As in all amputations, it is essential to drain the wound for at least 48 hours. When instead of re-amputation being performed the wound has simply to be closed, the operation is of the nature of a secondary suture, any sequestra being removed completely, the bone smoothed down if necessary, scar tissue removed, the skin undercut and sutured and temporary drainage provided.

In cases in which the stump has healed except for the persistence of a sinus, treatment depends upon the length of the stump and the condition of the skin and the bone. If the sacrifice of an additional inch or two will not affect the functional result, re-amputation is the most expeditious method, and is especially desirable if there are other defects such as the presence of extensive and adherent scars or of painful nerve ends. When, however, it is undesirable to shorten the stump, the sinus must be dealt with on the usual principles of treatment. If the scars are satisfactory and the sinus does not extend to the bone, it may be simply enlarged and curetted.

Usually, however, the skiagram shows the presence of one or more sequestra and the scars are often large and adherent. It is then best to excise the scars and the whole sinus, removing the new bone so that the end of the shaft is left clean and smooth. Of course it is often possible simply to enlarge the sinus and to extract one or more sequestra, but if this is done it is impossible to be quite certain that no necrotic bone remains, and any adherent scars are left untouched; only in special cases is such a procedure advisable.

In the earlier stages of the war it was common to find that a man had been subjected to three, four or more consecutive amputations, whereas in the later stages, in a large proportion of cases, a sound stump was secured after the second operation. This improvement resulted from the better methods of controlling sepsis, leading in many cases to an early secondary suture, and also to the improvements described above in the method of treating unhealed stumps. These were due largely to the work of Huggins at the Pavilion Hospital, Brighton, and to work done at the special military surgical hospitals.

Methods of Amputation.—When amputation is being carried out at a level at which plenty of skin is available, the flaps are naturally cut so that the scar will not interfere with the fitting of an artificial limb. In general, particularly in the lower limb, a single flap is preferable to two flaps and equal lateral flaps are particularly undesirable because they leave a terminal scar ; in the upper limb a terminal scar is of much less importance. There is still some difference of opinion as to whether the muscles should be included in the flaps or not. Huggins, whose experience is great, is against such inclusion on the grounds that any muscle left atrophies and forms a flabby, useless projection ; that inclusion of muscle renders it necessary to cut the bone shorter ; and that, if sepsis occurs, the scar tends to become adherent to the muscle and consequently puckered in. Around such a puckered scar eczema is common. On the other hand, it is claimed that any muscle placed over the end of the bone becomes converted into a fibrous pad which protects the end of the stump and prevents the skin from becoming adherent. In addition, in amputations in certain situations, such as the shaft of the femur, there is a great tendency to retraction of the muscles, leaving a stump with a conical extremity. If the muscle is included in the flap and stitched over the end of the bone, this retraction is prevented. Each case, therefore, should be considered individually. Flaps without muscle should be cut if there is any fear of sepsis, muscle being included when the field is aseptic and particularly when such retraction is likely to take place. If tendons are present at the site of the amputation, it is important that they should be cut short unless for some reason it is desired to attach them to the bone, otherwise they are likely to become adherent to the skin at the end of the stump and to move it upon the bone when the muscles with which they are connected come into action. Adherence of the tendons around the ankle to the extremity of the stump in a Syme's amputation is a frequent cause of failure to secure a good stump.

The method of dealing with the nerves has received much attention. After a nerve has been cut axis-cylinders grow out from its extremity into the tissues around and form a neuroma. If the nerve end is situated in scar tissue this neuroma becomes adherent and may be dragged upon in movement of the stump. The object should be to limit the neuroma and to prevent any axis-cylinders from extending into the tissues around, and at the same time to cut short the nerve so that its end is situated

well away from the scar at a spot where it is not liable to pressure. The method which has become accepted is to pull the nerves down, crushing each with a heavy pair of pressure forceps and then ligaturing this crushed region with a catgut suture ; by this means the nerve sheath is closed and the neuroma limited to its interior. The majority of painful stumps are due to nerve ends which are adherent, or from which axis-cylinders have extended into tissues around. The small nerves require treatment by this method just as much as the larger nerves. In a painful stump the exact locality of the pain may be determined by palpation, any tender nerve ends being cut short, crushed and ligatured in this way. In a few cases pain persists and may be due to a true "causalgia" such as is found in nerve injuries without amputation ; for this a section of the nerve at a considerably higher level is the only treatment. But as there may be a certain central or functional element in these cases success is not even then invariable. In painful stumps when a constant twitching or shivering occurs, a nerve end is usually present, and surgical treatment of this with subsequent immobilization of the stump in plaster of Paris for six or eight weeks will usually cure the condition.

Pain in the stump is not invariably due to nerve involvement ; it sometimes results from a chronic periostitis, perhaps with a sequestrum and a dormant septic focus. Such a condition may be detected by X-ray examination and can then be surgically treated. "Spurs" upon the bone are also an occasional cause of pain, and in some cases a painful nodule has been found to consist of an inflammatory mass around one or more non-absorbable ligatures. It should be an invariable rule that only absorbable ligatures are used in amputations.

The treatment of the bone and of the periosteum has aroused much controversy, as it has been thought that the occurrence of thickening and of spurs upon the bone end may be due to the way in which the periosteum has been treated. It may be considered as proved, however, that with one exception this is not true. It makes very little difference whether the bone and periosteum are divided at the same level, or a periosteal cuff is turned up and allowed to fall in over the end of the bone or the end of the bone is denuded of the periosteum. If a periosteal cuff is turned up, a blunt elevator should be used so that spicules of bone are not raised with it. Spurs upon the end of the bone are in some cases due to sepsis. The most frequent site is upon the cut end of the shaft of the femur, the

spur arising from the extremity of the linea aspera and lying in the muscles attached to this point (Fig 4). Such a spur is doubtless due to a disturbance of the periosteum along this line. It is best prevented by cutting away the muscles from their attachment to the last inch or so of the linea aspera in the stump.

As has already been mentioned, the tendency in the textbook amputation is to prescribe flaps that are too long. At the present day, in an aseptic amputation, the total length of the



Fig. 4.—Skiagraph of a thigh stump with a spur on the inner side springing from the linea aspera.

flaps should be equal to the diameter of the limb at the point of the section of the bone; this will allow of suture without excessive tension and without redundant skin. In some cases, in order to preserve length in the stump, it is necessary to suture under considerable tension; the method devised by Major Chapple of placing mattress sutures protected at each extremity by portions of india-rubber tubing is then useful (Fig 5). When muscle is cut in the flap this should be sutured over the extremity of the bone.

Artificial Legs.

Progress in the design and manufacture of artificial limbs has usually occurred as a direct result of great wars. The types of artificial legs used in England in 1914 were practically the same as those which were in use after the Crimean War, namely, the Anglesey limb and the Clapper limb. In both these the material used was as a rule well-seasoned willow, and the weight of the trunk was carried on the limb in the manner described below. In the Anglesey limb the movement of the ankle was regulated by a tendon inserted into the heel and fixed to the thigh piece above the knee; this plantar-flexed the foot beyond a right angle when the knee extended, but allowed the foot to dorsiflex as the result of the action of a spring when the knee flexed. In the Clapper limb the heel tendon was omitted, dorsiflexion beyond the right angle was stopped, but plantar-flexion was permitted by compression of a

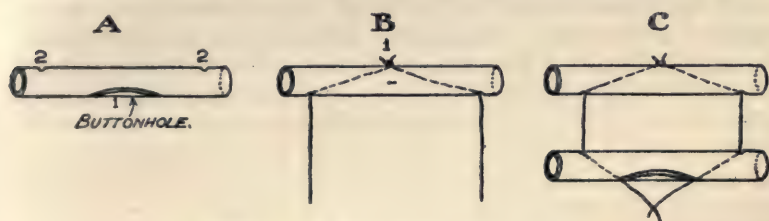


Fig. 5.—Tension stitches (Chapple).

coiled steel spring situated in the heel. In both types of limb the usual method of securing extension of the knee was to affix an elastic accumulator in front, but in some cases an internal spring replaced this.

When Queen Mary's Auxiliary Hospital was opened at Roehampton in 1915 an international exhibition of artificial limbs was held there, in order to make certain that all available knowledge of the subject was brought to this country, and also in order that, if necessary, assistance might be obtained from abroad to supplement the endeavours of the British limb makers to fit the already large number of men who were waiting for their artificial limbs. The output of the British limb makers was totally insufficient, and owing to difficulties of securing supplies and workmen it was found very difficult to expand it. At this exhibition certain American limbs were thought to show advantages, and it was found that American limb makers were prepared to come to England and provide limbs in large

quantities. This readiness of the American makers is to be ascribed to the advances in limb making which occurred at the time of the Civil War, to the relatively large number of railway and industrial accidents and to the absence of the strain of war in America.

Two American makers at once started branches in England, and took a large part in the making of artificial legs for disabled men. They introduced the American type of leg which, with important modifications and additions, has gradually replaced the Anglesey and Clapper types. In 1919 a Parliamentary Committee recommended that an endeavour should be made to standardize a type of artificial leg for each of the more frequent sites of amputation, and by 1920 this was carried out. The types which were decided upon, whilst based upon the American model, included all the results of experience gained at the various limb-fitting centres. They are strong, reliable, and mechanically efficient, and may be taken to represent the most up-to-date models of artificial legs manufactured out of wood or leather with steel joints. But even these types cannot be taken as final ; a limb made of wood or leather is necessarily somewhat heavy, and by the use of other materials such as aluminium alloys, a lighter limb will be evolved. Such light limbs are in fact being made and are in every respect satisfactory, but their manufacture in quantity, and at a reasonable price, is difficult so long as a simple design has yet to be perfected. The manufacture of a reliable light leg, of a weight of not more than 4 lbs. for an average thigh amputation, constitutes the immediate problem of artificial limb making.*

An artificial leg has to transmit the weight of the body to the ground when the patient is standing, it must move as nearly as possible as the natural leg moves when the patient walks, and at each step it must be automatically stable when the patient's weight falls upon it, and have no tendency to double up or collapse.

Only in special amputations can the whole weight of the body be transmitted to an artificial limb or to the ground through the surface at the termination of the stump (end bearing) ; more often a proportion only of the weight can be taken in this way (partial end bearing). In most cases the greater part of the weight must be transmitted to the artificial limb by pressure upon the bony points around the joint next above

*The only work published in England during the war giving a moderately complete account of the principles of construction of artificial limbs is Broca and Ducroquet's "Artificial Limbs."

the site of the amputation, that is, around the knee-joint in cases of amputation through the leg (tibial bearing), and around the hip joint in cases of amputation through the thigh (ischial bearing).

Complete end bearing is most valuable when it can be secured; Syme's amputation gives an almost perfect end bearing stump, and the patient with this amputation has the great advantage that he is to some extent independent of his artificial limb. The factors in a stump which favour end bearing are a division of the bone through cancellous tissue; a covering of thick fibrous or areolar tissue over the end of the bone; and a skin flap from a part which normally bears weight. In Syme's amputation, all these factors are present. In amputations through the knee, or through the condyles of the femur, they are also present and end bearing may be complete. In many other amputations, particularly those through the upper third of the tibia and the upper third of the femur, the extremity of the stump will carry a considerable proportion of the weight. Experience in the use of plaster of Paris peg legs has shown that most amputation stumps which are covered with a single long flap containing muscle are capable of bearing weight upon their extremity in a bucket made of plaster of Paris moulded accurately to the surface of the stump so that there is no friction.

In all amputations through the tibia above the level of a Syme's amputation the weight should be borne by the close fitting of the bucket around the internal tuberosity and tubercle of the tibia and the lower margin of the patella. The bucket must be fitted rather more loosely on the outer side, as the head of the fibula is unable to stand much pressure. Some limb-makers prefer to take the weight in this case through the leather thigh piece, either by compressing the thigh tightly in this fitting or by extending the bucket up to the level of the tuberosity of the ischium and so gaining an ischial bearing. This method of fitting renders the limb unnecessarily clumsy and heavy, and constricts the thigh muscles in a way that interferes with their use; it should be reserved for a few special cases in which the head of the tibia is intolerant of pressure.

In amputations through the thigh the weight is borne mainly by a close fitting of the top of the bucket under the tuberosity of the ischium; the edge of the bucket is fitted in exactly the same way as the ring of a Thomas' splint. The tuberosity of the ischium should rest either upon the edge of

the bucket or upon a rounded ledge in its interior, the rest of the bucket should enclose the stump, fitting it very accurately to within an inch of its extremity. If this circumferential fitting is very close, a certain amount of weight is borne by the friction between the thigh and the bucket ; it is, however, not usually practical to take a very large proportion of the weight in this way, because the result of the friction is to draw the skin upwards so that it is stretched over the end of the stump. If the scar is linear, mobile and situated anteriorly, posteriorly or laterally, a considerable amount of tension upon the skin can be borne, but if there is a terminal scar, particularly if it is extensive, thin or adherent, this tension is very likely to produce ulceration.

Limb for Amputation through the Hip-joint.

For disarticulation at the hip joint and for very short thigh stumps a limb is made similar to that for thigh amputations, and attached by external steel hinge joints on the inner and outer sides to a leather socket which encloses and fits accurately one half of the pelvis. This leather socket itself is held on by a steel pelvic band and is strengthened by a vertical steel passing round its inner border to which the inner joint is attached. The outer joint is attached to the pelvic band by a prolongation upwards of its upper arm. Both hip and knee joints are fitted with locks. The patient invariably requires the hip locked when he walks, in some cases he is able to keep the knee free, in some he requires it locked also.

Limb for Amputation through the Thigh.

A thigh bucket should fit the entire stump accurately, and it should do this without deforming the shape of the stump. Looked at from the front the inner side of the bucket should be slightly concave, corresponding with the natural concavity in the adductor region, but exaggerating this slightly. Looked at from the side the posterior surface of the bucket should also be concave, again slightly exaggerating the normal concavity in this situation. The reason for exaggerating these concavities is that by so doing the ledge upon which the tuberosity of the ischium rests is emphasized, and at the same time rounded. The upper border of the bucket is cut away a little on the inner side in order to avoid pressure upon the perineum. From this, its lowest point, the edge of the bucket rises slightly posteriorly, where it rests against the tuberosity of the ischium. The anterior edge of the bucket slopes upwards and outwards

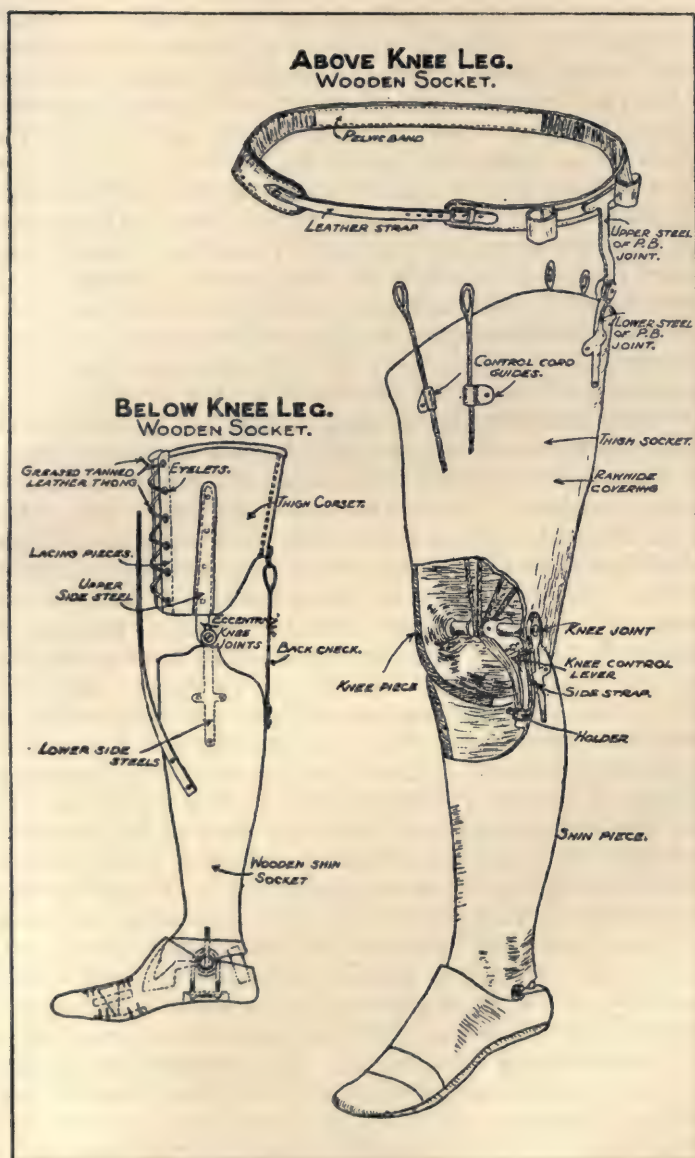


Fig. 6.—Artificial legs, Ministry of Pensions standard pattern.

so that on the outer side it reaches as high as the great trochanter, against which it should fit very accurately. As a rule the whole thigh piece of a wooden leg is made with the bucket out of a single piece of wood. In order to make adjustments for length, however, the thigh piece may be cut across transversely, the upper section or bucket being united to the lower section or knee piece by dovetailing.

The simplest method of attaching an artificial limb for an amputation through the thigh is by means of a brace passing over both shoulders and attached to the upper margin of the bucket in front and behind. The great objection to this simple brace is that any movement of the limb at the hip joint will put tension upon the brace on one aspect of the body, and relax the tension upon the opposite aspect; either the brace must become very tight on one aspect, or it must slip backwards and forwards on the shoulders. The same criticism applies to a second method of attaching the limb, namely, to a waist belt or pelvic belt by straps attached to the margins of the bucket. The form of suspension now almost invariably used is that which was introduced into England in the American leg; in this the braces which pass over the shoulders terminate in two loops formed of stout leather thongs, the end of each loop being attached to the front and back of the braces. The loops pass below through the thigh piece, in which they run under a pair of pulleys which form part of the knee mechanism. When the limb swings the movement comes upon these leather thongs which roll under the pulleys, and no friction upon the shoulders occurs; this method of suspension, in addition to the comfort resulting from the disappearance of friction, enables the suspensory mechanism to assist in producing extension of the artificial knee-joint in the manner described below. When the amputation stump is very short it tends to slip out of the bucket, and some additional method of attachment is necessary. This usually consists of a steel pelvic band, which encircles two-thirds of the circumference of the pelvis just below the anterior superior spines of the ilium, and is completed in front by a leather strap and buckle. This pelvic band is hinged to a vertical steel which is securely fixed to the outer side of the thigh bucket.

Mechanism of the Knee-joint.—In order that the gait with an artificial leg may be as natural as possible the knee-joint must be freely mobile. It is possible to walk securely upon a level surface without active extension of the knee-joint by

allowing the knee to hyperextend, the joint locking in this position because its centre of movement is behind the line through which the weight of the body passes and because the posterior ligaments and crucial ligaments prevent the knee extending further. The first principle of securing stability in an artificial leg is to centre the movement of the knee well back and to allow the joint to hyperextend. It is quite possible to arrange a suitable knee-joint with no other mechanism than this. In such a simple joint the patient swings the leg forward by a pendulum action; he allows the weight to come upon the leg as soon as the knee has extended fully, and all that is necessary is to make sure that the pressure will be exerted in such a way as to force the knee into the hyper-extended position; the latter point is secured by attaching the foot in such a way that it will not dorsiflex as far as the right angle, that is, it is set slightly in the position of a talipes equinus. The strain thrown upon the knee-joint by the production of hyperextension when a patient has a slight degree of talipes equinus is well known to orthopædic surgeons.

This simple pendulum action of the knee has two objections: first that it is somewhat slow, and so necessitates a rather laboured gait; and second that the patient often feels a sense of insecurity due to the fact that there is no active force which can be used to extend the joint if the swing does not extend it fully. For these reasons it is customary to supply one or two additional means of securing extension of the knee; the simplest of these is an accumulator or spring as an extending force. A simple accumulator of elastic may be attached to the front of the thigh and the front of the leg so that this has a constant tendency to extend the knee. The objection to it is that the force is still in action when the patient sits down, and if the spring is strong he may find that the moment he raises the foot from the floor the leg tends to spring forward. It is better to use an internal spring which is so centred that it will only extend the knee from a position of flexion up to the right angle, having its action abolished or reversed at this point.

The second method used for extending the knee is by means of the sling; the pulleys, under which the thongs attached to the slings pass, form part of that section of the knee-joint which is continuous with the leg piece, and are situated in front of the axis of the joint. When tension is put upon the thongs a leverage is exerted which tends to extend the knee.

Tension may be put upon the sling by the patient's own action, that is by elevating the shoulders, but even without this voluntary action the weight of the limb produces tension upon the sling whenever the foot is off the ground, and for this reason directly the foot leaves the ground a force comes into action which helps to extend the knee.

In many cases it is advisable to fit a knee lock so that the wearer can fix the knee in the extended position at will. Sometimes this fixed position is required in walking because the control of the stump is poor. More often it is required by the patient for use in prolonged standing. Many attempts have been made to invent a mechanism which will automatically lock the knee when the weight comes upon the limb with the knee flexed. So far the best of these is a band brake passing round a drum in the centre of the knee joint, but although this has been proved to work satisfactorily it is heavy and difficult of adjustment. An automatically stable knee remains one of the problems of prosthesis of the lower extremity.

Mechanism of the Ankle-joint.—The ankle-joint moves comparatively little in normal walking upon level ground. Its total range of angular movement is not more than 20° to 30° , the maximum dorsiflexion being only just beyond the right angle, and the maximum plantar flexion about 15° to 20° beyond the right angle in the other direction. It is quite possible to fix the artificial ankle-joint so that it is immobile and even so to get a very natural walk. It is usual, however, to allow a slight rocking movement of the joint, the movement being limited by the compression of anterior and posterior rubber buffers placed between the foot and leg. As already mentioned, in order to secure stability of the knee, dorsiflexion in the artificial ankle-joint must not be allowed to reach the right angle; practically the extreme of dorsiflexion is that position which the foot assumes when the patient stands upright in an ordinary boot with such a heel as he usually wears and with the knee pressed well back; from this extreme position in one direction, further plantar flexion of 20° is permitted. Many other designs of ankle movement are in existence including some in which a lateral movement is allowed, and some in which a tendon attached from the back of the knee to the heel secures plantar flexion of the foot when the knee is extended and a dorsiflexion when the knee is flexed. All these variations of joint have been superseded by the simple one already described.

Limb for Amputation through the Knee.

When the leg has been amputated through the knee the lower end of the stump is larger than the part immediately higher up; for this reason it is impossible to slip the stump into an entire wooden bucket. The bucket must be made of leather which laces up at the front of the thigh. The leg must be attached to the thigh piece by lateral steels and the knee-extending mechanism must be placed on the outside; these alterations render the limb clumsier and heavier than that made for the ordinary thigh amputation.

Limb for Amputation through the Leg.

As already mentioned in amputations below the knee the bucket is fitted closely around the head of the tibia and below the patella; its upper margin must be cut down well at the back in order that the hamstring tendons may not be compressed when the joint is flexed. As the patient possesses a natural knee-joint, a mechanism to extend the joint is unnecessary except in the case of very short stumps; in these a strap attached to the sling may be fixed to the front of the leg bucket. It is also unnecessary to limit dorsiflexion of the foot to the right angle; by allowing this movement to extend until the angle between the leg and the foot is about 80° the patient's comfort will be increased, and the strain upon his knee joint diminished. It is customary to attach the leg by fitting lateral steels jointed at the knee, the thigh sections of which are fixed to a leather corset which encloses the thigh; this is very secure but somewhat heavy and can be dispensed with in some patients who have good stumps below the knee. Limb-makers find a difficulty in fitting the simpler method of attachment which consists of a small leather collar encircling the thigh just above the knee to which the leg bucket is attached by lateral straps of leather. The reason for their difficulty is that they fix the foot in the equinus position and that this throws a strain upon the knee making it hyperextend. The patient's natural knee joint cannot stand this strain, which is therefore counteracted by tying the back of the thigh corset to the back of the leg bucket by a popliteal check cord. If, however, the foot is allowed to dorsiflex, the necessity for this check cord disappears and the thigh corset and lateral steels can be dispensed with.

Limb for Syme's Amputation.

A Syme's amputation leaves two inches or more between the end of the stump and the ground ; there is, therefore, ample room for the introduction of an artificial ankle-joint of the same pattern as that already described. All that is necessary is to enclose the leg from the knee downwards in a well-fitted leather sheath to the lower end of which an artificial ankle and foot are attached by steels.

The actual manufacture of a limb for Syme's amputation is not easy, because the strain thrown upon the attachment of the steels to the bucket is very great. Owing to this difficulty a standard pattern of limb for this amputation has even now not been designed. The simple elephant boot without foot or ankle movement remains the most satisfactory appliance.

Levels of Amputation in the Lower Extremity.

Amputation of the Foot.—Amputation of any individual toe leaves so small a disability that it may be freely performed for any injury or painful condition ; even the big toe may be thus sacrificed. When more than one toe has to be amputated the effect will depend upon the toes removed, but it may be said generally that two toes may be sacrificed freely ; if three or four have to be amputated the patient will probably be better off if all the toes are removed at once. In amputations of the toes, as in all foot amputations, the scar should be kept in a dorsal position and the stump covered entirely with sound skin ; a wound which has healed by granulation is very likely to give trouble.

Lisfranc's amputation and similar amputations at the tarso-metatarsal junction leave good stumps provided that the scar is dorsal and sound ; for this amputation and for amputations of the toes no artificial foot is necessary, and the patient can wear an ordinary boot in which the front part of the upper leather is stiffened.

Chopart's operation is not a good one, the tendons of the tibialis anticus, long extensors and peronei lose their anterior attachment, and the stump is pulled by the tendo Achillis and tibialis posticus into an equino-varus deformity, so that the patient instead of walking on the under surface of the heel walks upon the outer part of the anterior extremity of the stump. In most cases of Chopart's amputation an artificial foot cannot be fitted, and re-amputation is required. When, however, the tendons of the tibialis anticus and peronei have been reattached and the stump kept in a good position, the

result may be satisfactory. Pirogoff's amputation and similar amputations in which a part of the os calcis is retained in the flap, have no advantage over Syme's amputation when an artificial foot is to be worn; these amputations are designed to avoid shortening and to keep the prominence of the malleoli, so that a simple boot can be worn instead of a more elaborate artificial foot. From this point of view they have advantages for the poor hospital patient who may find it impossible to get an artificial foot, but if such a foot can be obtained the preservation of length is a disadvantage because it prevents the introduction of a good artificial ankle joint. In addition, in military surgery, in which the risk of sepsis must always be present, the preservation of a piece of bone in the flap and its fixation over the cut end of the tibia and fibula have proved to be a danger, for if necrosis occurs, or if the bone does not unite, a re-amputation will probably be necessary.

Syme's amputation is undoubtedly the best amputation in the lower limb. It is more difficult than is a straightforward amputation through the middle of the leg, but this is much more than counterbalanced by the fact that a patient with a good Syme's amputation can walk ten to fifteen miles, run, jump and play such games as tennis and golf almost without his disability being noticed.

Such success can be claimed for a Syme's amputation only if it is a good one; there must be two inches between the end of the stump and the ground, the bone must have a clean flat under surface and must be covered with a closely fitting flap, the skin of which is quite sound, having no spots that are tender upon pressure (Fig. 7). The common faults in a Syme's amputation are that the bone is cut too long, the flap is too large so that it leaves a flabby end to the stump, and the plantar nerves are often left in the flap, which may for this reason be acutely sensitive. The classical incision leaves too large a flap; the best incision is an elliptical one, the angle between the two parts of the classical incision being abolished by taking the anterior incision up to a higher level and by carrying the lower incision to within $\frac{3}{4}$ in. of the point of the heel. The tibia and fibula should be divided a good $\frac{1}{2}$ in. above the level of the articular surface of the ankle-joint, the nerves should be dissected well back, and the main posterior tibial nerve crushed, ligatured and divided above the level of the malleoli. The tendons should be cut short so that they do not adhere to the flap. It is most important that the heel flap should have a good blood supply, and for this reason great care

must be taken to cut very close to the bone and thus avoid injury to the vessels. If the blood supply to the flap is insufficient its margins may slough, and a re-amputation through the leg will probably be necessary. In cases in which the posterior tibial artery has already been ligatured or in which



Fig. 7.—A good Syme stump with complete end bearing and $2\frac{1}{4}$ inches clearance between the end of the stump and the ground.

there is much scarring of the lower part of the leg sloughing of the flap is very likely to occur. These conditions and scarring of the heel should be held to contraindicate a Syme's amputation, an amputation through the middle of the leg being performed instead. Suppuration of a Syme's amputation is a very serious accident ; if any necrosis of the bone occurs the

stump will almost certainly not bear weight upon its end, and the patient must either wear a clumsy limb with bearing upon the head of the tibia, or he must have a re-amputation. Experience in France showed that the best results, in the presence of sepsis, were obtained if the heel flap was left unsutured at the time of operation, and turned back and packed with gauze for three or four days. It was then fixed in position by "secondary suture."

Drainage of a Syme's amputation by puncturing the heel flap has been advocated; this is a mistake, for it leaves a scar in the middle of the chief bearing surface which may considerably interfere with the comfortable fitting of an end-bearing limb.

Amputation through the Leg.—Up to a certain point the longer the stump is below the knee the better, but a very long stump has certain disadvantages without corresponding good points. In long stumps the skin over the end has often a poor circulation, and ulceration is frequent. In addition, the leg bucket must be made wide enough to enclose the stump, with the result that the ankle of the artificial limb has to be made thicker than that of the natural leg. A stump which contains seven inches of the tibia measured from the knee-joint line is the best. The best flap in the leg is a single one. It may be cut from whichever aspect is most convenient, but an anterior flap yielding a posterior scar is usually considered best. The length of the stump should not be shortened in order to obtain an ideal flap. The flaps must not be too long: they should just cover the bone snugly without tension but without leaving any flabby end of the stump. When the flaps have been cut long this flabby termination of the stump has often a poor circulation and tends to ulcerate.

The crest of the tibia should be rounded with the saw or with a file, and the fibula should be cut slightly shorter than the tibia. A long fibula is a great inconvenience in fitting an artificial limb.

It is worth while preserving even very short stumps below the knee. The test of utility of such a stump is to flex the knee to a right angle, and then try whether a finger can be hooked around the stump and thus secure a hold. It will be found that in most cases a stump containing only two inches of tibia measured from the joint margin answers to this test. In these short stumps there is a tendency for the fibula to tilt away from the tibia and project, so that it is a good plan to remove the whole of the fibula. In this way a piece of bone is removed which stands pressure badly, and at the same time the

bulk of the stump is diminished, so that a flap which would otherwise be too small may suffice. The preservation of these short stumps below the knee is of very great importance because the patient, having his own knee joint, is able to walk up and down stairs and on irregular ground in a way that would be impossible if the amputation were through the thigh. For this reason it may even be desirable to leave such a short stump to heal by granulation, a thin adherent scar resulting. It is then possible to fit an artificial limb or in case of failure to re-amputate above the knee or to fit the leg upon the flexed knee.

Many leg stumps become flexed at the knee joint, extension being impossible, but this is due to a fault in early treatment, as all leg amputations should be kept upon a back splint until the wound is healed. If flexion has become established it can usually be corrected by daily stretching with the hand and by the use of a posterior splint. In some cases, however, operative treatment is required, the obstruction to extension being due to a contraction of the attachment of the gastrocnemius and of the posterior ligament of the knee joint. It is then necessary to divide these as well as the hamstring tendons and the ilio-tibial band before the knee can be straightened. The operation should be carried out through two longitudinal incisions on either side of the posterior aspect of the joint. Care should be taken to preserve the popliteal vessels, as if these have to be ligatured, sloughing at the end of the stump is very likely to ensue. If every effort to extend the knee fails the joint may be left flexed to a right angle and an artificial leg fitted as for a knee joint amputation. This is, however, a confession of failure, leaving the man to lose the advantage that he should have gained by the preservation of the knee joint. In amputations through the leg in cases where the knee is ankylosed re-amputation through the condyles of the femur is usually advisable.

Amputation through the Knee.—From the surgical point of view this operation has objections. When sepsis is present it is a very risky procedure, and even under good conditions it requires very large flaps which can seldom be secured in cases in which the knee joint cannot be preserved. In order that a good artificial limb may be fitted, the end of the femur must be uninjured and it must be covered with healthy skin, the scar lying over the popliteal aspect of the bone; therefore, unless large clean flaps can be obtained, it is better to amputate at a higher level. The artificial limb for a knee joint amputation is somewhat clumsy and heavy, but an amputation through the

condyles of the femur at the Stokes-Gritti level is at least as easy to fit and enables the patient to walk as well. It seems, therefore, that this latter amputation has to a large extent replaced that through the joint.

Amputation through the Thigh.—The best amputation above the knee is that in which the bone is divided through the upper part of the supra-condylar ridges, and covered with an anterior flap. The Stokes-Gritti operation at this level in which the superficial half of the patella is preserved and pinned over the cut end of the bone is a very good one, provided that asepsis can be secured. If the wound suppurates, the use of the patella is a danger, for it may fail to unite with the femur, or necrosis may occur and the removal of the necrosed bone become very difficult; therefore, as a rule, the patella is removed, but the fibrous tissue around it should be retained and stitched over the end of the bone.

An objection made to this amputation is that the length of the stump interferes with the knee mechanism of the artificial leg. The good leverage given by the long stump and its ability to take end-bearing more than compensate for this disadvantage, and it is one that can be overcome.

Above this level the only rule for thigh amputations is that every inch of bone must be preserved. With this end in view flaps should be cut from wherever skin is available, always avoiding if possible the inclusion of scars in the flap. If there is any choice a single long flap is the best, and should be cut from the outer side, so that the scar becomes internal where it is least liable to pressure. In thigh amputations there is a great tendency for the muscles to retract, leaving the end of the bone prominent under the skin; therefore, the flaps should be cut deeply and the muscles sutured over the bone. As in amputation through the leg, flaps should not be too long, and should be sutured closely but without tension.

There is a great tendency for a thigh stump to become abducted and flexed at the hip joint; this will interfere seriously with the fitting of an artificial limb. In many cases the deformity has arisen because a septic stump has been left to ulcerate and granulate for a long time between the primary amputation and the final trimming which results in healing. This is a strong argument for a line of surgical treatment which will accelerate healing of the stump. The position assumed by the stump when the patient sits in bed or on a chair is an important factor in causing the deformity; in all thigh amputations this contraction at the

hip should be guarded against from the first by daily stretching and manipulation. The use of the stump in a temporary peg leg also prevents this contracture arising.

When the patient stands he can hide a considerable degree of abduction and flexion deformity by tilting the pelvis and hollowing the lumbar spine ; it is necessary, therefore, to test for this deformity by a routine method known as Thomas' test (Fig. 8). The patient should lie upon a hard table, without pillows and with the pelvis straight, then, ignoring the stump, the healthy hip is flexed fully until the thigh is in contact with



Fig. 8.—Method of testing a thigh stump for flexion deformity of the hip. Extension was in this case complete.

the abdomen ; in this position lordosis is abolished and the full degree of flexion deformity can be estimated. It is often found that the patient can extend the hip if abduction is permitted, and therefore the level of the anterior superior spine must be carefully noted during the test.

When the deformity is once established it must be overcome by daily stretching ; a routine method is necessary for this. The patient should lie on a hard table with the sound hip flexed, a strap is then passed over the front of the stump and through two slots in the table, being attached below to a pedal, the masseur by pressing on the pedal with his foot

forcibly extends the hip, both his hands are free to manipulate the stump and thus to overcome the abduction. A second method, which is not so good, is to place the patient upon his face and to hyperextend the hip in this position. Occasionally this deformity requires operation; it is then necessary to divide the tensor fasciæ femoris, sartorius, the rectus femoris, the muscles attached to the great trochanter and digital fossa, the ileo-psoas, and the anterior part of the capsule of the hip joint; these may all be divided through an incision extending for about four inches vertically downwards from the anterior superior spine.

In order that a thigh stump may secure a proper hold in the bucket of an artificial limb, it must measure at least two inches on its inner side below the perineum; this is equivalent

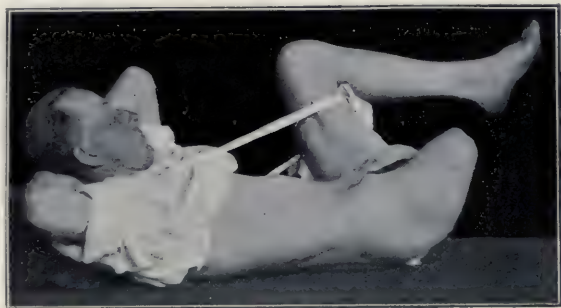


Fig. 9.—A similar case with flexion contracture.

to about five inches of femur measured from the tip of the great trochanter. If the stump is shorter than this it will slip out of the bucket when the patient swings the leg. In these very short stumps there is a great tendency to flexion and abduction deformity, and because little leverage can be obtained the correction of this deformity is specially difficult. When the stump is too short to secure a proper hold in the bucket, it must be kept flexed to a right angle and entirely enclosed in a pelvic fitting, an artificial hip joint being attached. The artificial limb is then similar to that used for a hip joint amputation.

Amputation through the Hip Joint.—The best hip joint amputation is that carried out through a racket incision with the vertical part in front over the vessels. The scar should cross the buttock well away from the perineum and from the tuberosity of the ischium; the muscles should

be preserved in the flap so that a good pad is left over the region of the acetabulum ; the nerves, however, particularly the great and small sciatic and the anterior crural, must be cut very short. The Furneaux-Jordan operation has become obsolete. It leaves a flabby stump which is incapable of controlling an artificial limb and is only an embarrassment because it must be folded up and enclosed in the leather case.

Artificial Arms.

The function of an artificial leg is simple ; it has to bear the patient's weight and to carry out the movements of walking. An artificial arm is a very different thing, either it is purely ornamental or it is used as a tool to convey movement from the stump to anything which the patient holds with it. It has been found necessary to impress this clearly upon men who have lost an arm. As a rule an artificial arm is expected to do too much.

In 1914 only very simple types of arms were in use in the United Kingdom. They consisted of a bucket fitted to the stump with a simple hinge elbow joint, sometimes capable of being locked in several positions and with a dummy hand detachable and capable of being replaced by a hook or a ring. At the Roehampton Exhibition the Carnes' arm from America was demonstrated, in which certain movements of the trunk and of the stump were used to actuate the artificial arm, so that in an arm fitted for an amputation above the elbow, the artificial elbow could be flexed, the forearm supinated and the fingers opened and closed. Many of these arms were supplied. They proved, however, a disappointment partly because the weight of the mechanism in the hand was excessive, partly because the movements, although mechanically very clever imitations of the natural movements of the elbow, forearm and hand, were not really very useful movements in everyday life or in work. There followed the progressive development of the so-called mechanical arms, made by the limb-makers in England, who utilized the movements of the trunk and stump to operate the artificial arm. This development led to the production of a large variety of arms of the mechanical type. It was soon found that mechanical complexity if combined with sufficient strength necessitated considerable weight, so that the arm tended either to be too heavy or to be too fragile for use in manual labour. A second type developed along different lines and became known as the worker's arm ; in this the external shape of the arm was ignored,

a skeletal structure replacing it and serving to transmit the movements of the stump directly to the hook or other appliance which was used for the actual purpose of the work. In a worker's arm a dummy forearm and hand could be attached in order to complete the external appearance of the arm. Eventually these two types of arm were combined, the mechanism of the first type being used, whilst the structure is skeletal, the forearm and hand portion being only an easily detachable dummy. A typical arm of this type for above-elbow amputation consists of a bucket which fits the stump and is attached by a simple harness of straps passing over the shoulder and under the opposite axilla ; it was considered essential that this harness should be so simple that the patient could slip the arm on and off without assistance. To the lower extremity of the bucket a steel elbow joint is fixed, and this can be flexed by a cord and locked in any of several positions. This lock may be worked with the sound hand, or a second cord from the harness may be used to drop it in place and to lift it out. Below the elbow a central rod may be used to carry a hook or any other appliance that is desirable, or this rod may be replaced or covered by a dummy forearm section bearing on its extremity the wrist plate into which the hand is screwed.

Another type of arm was developed known as the dress arm, in which strength is sacrificed to lightness and the external shape of the natural arm is closely copied. A mechanism for the elbow and hand may be inserted provided that this does not involve too much additional weight.

It will be seen that in artificial arms there is room for a great diversity of design and great complexity of structure. It is impossible to give more than a brief outline of the principles of construction. The movements of the shoulder, chest and stump, which can be used for transmission to the artificial limb are the following :—

- (1) Approximation of the shoulders anteriorly tightening a cord stretching across the back.
- (2) Expansion of the upper part of the chest tightening a cord across the front.
- (3) Elevation and depression of the shoulder.
- (4) Abduction of the stump at the shoulder.

These movements can be transmitted either by a Bowden brake wire or by a simple leather thong. A few other points about an artificial arm require mention. In the first place in amputations through the shoulder or very high up

in the arm, an artificial shoulder joint is necessary; this usually allows no movements and does not permit of rotation. The arm socket may be divided transversely and the upper or lower sections made to revolve upon each other so as to allow the patient to twist the arm into different positions.

It is usual to attach the hand, or any appliance used instead of it, by means of a screw of standard thread; instead of this any one of the large number of snap-catches may be used but the snap-catch should be capable of taking an adaptor fitted with the standard thread.

The hand most often used for a dress arm is one carved out of wood with fixed fingers, each strengthened by one or more inlaid tenons, the thumb, which is kept approximated to the index finger by a spring, being the only mobile part of the hand. Sometimes one of the cords is attached to the thumb so that the patient can voluntarily open this to grasp a small object.

For a working arm the "Openshaw hand" is generally used. In this the little and ring fingers are flexed into a hook form, and strengthened with steel so that they may be used for carrying. The index and middle fingers are jointed and can, if necessary, be moved out of the way.

Mechanical artificial hands have been designed in large numbers, but most of them have proved to be of little or no use. The mechanisms are too complex for description. For working purposes the hand must, as a rule, be replaced by some other appliance; the simple hook of C pattern has proved by far the best of these, but many appliances are in use, some having a general utility, others being made for some special occupation.

Levels of Amputation in the Upper Extremity.

Amputation of the Hand.—In injuries of the hand conservative surgery has proved to be most important. A hand in which two digits, or parts of two digits, remain is almost always of greater use than any artificial hand. For this reason early amputation of the hand or any part of it should only be carried out when it is necessary as a life-saving device, or when the destruction is so complete that it is clear that no mobile digit can remain. Even then the immediate amputation should be strictly limited to the parts destroyed, and no attempt should be made to carry out a formal amputation. The final decision as to the portion of the hand to

be retained is generally left until a late stage of treatment, when the wounds have healed and the function of the hand, as a whole, can be considered.

The loss of the thumb constitutes a very great disability, and it should only be sacrificed when it is hopeless to save any part of it, even in a mutilated state. Because of the importance of this digit in opposition to the fingers, a stiff thumb with all the joints ankylosed and all the long tendons lost is better than no thumb at all. If necessary, reparative operations can be performed; an arthroplasty of the carpo-metacarpal joint may restore mobility, and suture or transplantation of tendons may be used as a method of regaining active movement. The stump left by amputation at the metacarpo-phalangeal joint is a useful one, because it has power of opposition, so that this section of the thumb should be kept unless the metacarpal bone and all the short muscles have been destroyed.

In amputating individual fingers it is best to use a long palmar flap and so leave the scar on the dorsal surface. Such part of the finger as is actively mobile should be kept, and the long tendons should be sutured to the end of the stump. The digital nerves often become tender and they should always be crushed and shortened in finger amputations. When a finger is being removed at the metacarpo-phalangeal joint, or at a higher level, the method of amputating must depend upon the nature of the injury. If the metacarpal bone is intact the finger should be taken off through the joint, provided that there is sufficient skin to cover the stump, but if there is an ununited fracture of the metacarpal bone it is better to remove the distal fragment. When the little finger is amputated in this way, the short muscles, if they are complete, should be sutured to the side of the extensor tendon of the ring finger.

When more than two fingers have been amputated it may sometimes be advisable to remove portions of the metacarpal bones, deliberately forming a lobster-claw hand similar to that seen as a congenital deformity. A hand in which the thumb and ring finger, or ring and little fingers have been preserved in this way may be very useful for almost every variety of work.

The preservation of a single digit is useful, for it is possible to attach an apparatus in which this digit can be opposed to a surface to give a grip and its point made to meet a projection, so that small articles can be held. When no digit remains a mobile stump containing some part of the carpus and metacarpus may be useful either in itself, or as a means of actuating the grip of an artificial hand.

Amputations at the Wrist.—In amputation through the wrist-joint the preservation of the inferior radio-ulnar joint leaves full pronation and supination, and as the styloid processes remain the bucket of the artificial appliance can be fitted around them and is thus held on securely; this amputation is, therefore, a good one. Some limb makers object to it because it is difficult to fit, and because the artificial hand must be made to project so that the limb is a little longer than the natural one. These, however, are small points compared with the increased gain in functional utility.

Amputations through the Forearm.—Every possible inch of the forearm should be preserved because the long stump increases the leverage applied to the artificial arm, and because in a long stump containing more than half the length of the forearm a certain amount of pronation and supination will remain. The possibility of utilizing the forearm muscles by the operation of "cinematization" described below, renders it advisable that these muscles should be preserved down to, and even beyond, the end of the bones, at least in the primary amputation. If at a later stage the muscles are found to be useless the stump can be trimmed up by a very simple operation. It does not matter much how the flaps are arranged in this or in any amputations in the upper limb; it is seldom that scars give any trouble in the fitting of an artificial arm. When only a short portion of the forearm remains it is difficult to utilize this to move an artificial limb, because when the elbow is flexed the antero-posterior diameter of the upper part of the forearm is increased and a bucket which fits tightly with the elbow extended is too tight when the elbow is flexed, or if it fits with the elbow flexed is too loose when the joint is extended. The usual result is that the artificial limb tends to be pushed off when the elbow is flexed; this difficulty arises when the stump of the ulna is less than four inches long, and when less than two inches of the bone remains the stump disappears altogether in the flexed position and fitting is impossible.

Two surgical procedures have been adopted to overcome this difficulty: the more drastic is to re-amputate the arm above the elbow, the less drastic is to excise the whole of the forearm muscles from their attachment to the condyles of the humerus. The latter operation has not proved very useful.

It is possible to fit most of these stumps by the method adopted by Williams, and, even if this is not possible, an artificial elbow can be introduced, the forearm stump being

ignored. The retention of the elbow joint allows of a secure fitting around the humerus which resists traction and rotation in a way that is impossible with a stump above the elbow.

The ordinary method of attaching an artificial arm for below-elbow amputations is by lateral steels jointed at the elbow and fixed by a section which laces around the arm. Williams' method of fitting consists in the enclosure of the stump in a bucket of hard leather, attached to the upper margin of which are two flaps of softer leather which lace in front of and behind the arm, and are fixed at such an angle that the elbow is not allowed to extend fully; they secure a firm hold upon the supracondylar ridges of the humerus and no other harness is necessary. In Williams' arm a C-shaped hook of particular pattern is used. With the simple arm and this hook appliance the inventor has been able to work as a collier for thirty years, and it may be said that this arm has proved to be the most successful of all working arms.

Amputations through the Elbow Joint.—The difficulty in amputations through the elbow joint is a surgical one; the condyles of the humerus are very wide and a long flap is necessary to cover them. Such a flap can seldom be obtained even in suitable cases. The limb fitters urge another objection, namely, that the fitting of the stump is difficult and that an external artificial elbow joint is necessary and is weaker than the type of joint fitted in an artificial arm for an amputation above the elbow. The fact already mentioned that a secure hold can be obtained above the condyles of the humerus is a sufficient advantage to counterbalance any difficulty in fitting; therefore, an amputation through the elbow is a good one when it is possible and when none of the forearm can be saved.

Amputations through the Arm.—The one requirement in amputation through the arm is to save every possible inch of bone; here, as in the forearm, muscles should be preserved in view of their possible subsequent use. The large nerves in the arm lie in exposed positions and are particularly liable to develop painful neuromata; they should always be crushed, shortened and ligatured as already described.

Amputations through the Shoulder.—A very short arm stump is unable to transmit movement to the artificial arm, practically two inches of stump measured from the anterior axillary fold being necessary for this purpose. This fact, however, does not modify the method of amputation; everything possible should be preserved, whether the stump is likely to have useful mobility or not. Patients with very short arm stumps

and those with amputations through the shoulder joint seldom wear artificial arms except for appearance. If the upper end of the humerus is kept the symmetry of the shoulders is preserved—a considerable advantage to a patient who does not care to wear an artificial limb for which he can find no use.

Cinematization of Amputation Stumps.—The operation of cinematization of amputation stumps acquired considerable publicity in the later stages of the war, but its real utility is still in doubt. The principle of the operation was suggested by Fanghetti, and most of the experimental work has been carried out by Putti at Bologna. The muscles in the stump are attached either to loops in the skin (*ansa motor*) or to artificially formed projections (*clava motor*), and these are then used to work the artificial limb. The latter class of motor has proved the more powerful and is now almost exclusively used. An example of the method is the stump obtained by amputation immediately above the elbow, in which the biceps and the brachialis anticus are retained together with a small portion of the radius to which they are attached, forming the anterior motor; while the triceps is kept posteriorly with an attachment to a portion of the olecranon and forms the posterior motor. Fitzmaurice Kelly, who has done most of the experimental work in England, found that motors containing bone were the most useful. The real difficulty of this method has proved to be the manufacture of a suitable and useful appliance, those used by Putti having been too light. Kelly's account of his method may be consulted for details of the procedure, which must still be considered as in the experimental stage.

Temporary Artificial Limbs.

The use of temporary artificial limbs for the lower extremity gradually became more and more popular until it is now the custom to insist that every man who has lost a leg shall be supplied with a temporary limb at as early a moment as possible, and that he shall be made to wear this limb and discard crutches. The reasons for this are that it is a good thing for the stump to be brought into early use and thus to keep the muscles that will be used in walking in good condition; that the crutch habit is avoided; that contractures of the stump are less likely to arise; and that shrinkage of the stump into its final form is expedited.

The first three of these reasons are obvious; the last requires some further explanation. Every stump in the lower limb

tends to shrink for a considerable time. This results partly from the fact that the function of many of the muscles of the stump has disappeared, but this is not the whole reason. A considerable portion of the shrinkage results from the pressure of the bucket of the artificial leg. For this reason the mere passage of time is insufficient to secure shrinkage. The pressure of an artificial limb bucket is necessary, and the better the bucket fits the stump the more satisfactory will be the shrinkage.

Many types of temporary leg have been used during the war. Perhaps the most popular has been that which is made out of a cone of fibre, cut and padded at the top to make it fit the stump, and fastened at the lower end into a circular wooden block. These fibre legs have been made and supplied in large numbers by the British Red Cross Society. Whilst they have been found to be extremely useful and convenient, because they could be made by amateurs and easily fitted, they are not all that could be desired from the surgical point of view. They do not fit the stump accurately and therefore do not give as much assistance in shrinking the stump as do better fitting buckets.

The best form of temporary artificial leg has proved to be that in which the bucket is made of plaster of Paris. The leg shown in Fig. 10 is made in the following way. The wooden framework is made of two crutch sticks attached at the lower end to a block of wood $2\frac{1}{2}$ in. in diameter. The crutch sticks are cut at the top so that when the end block is level with the heel of the boot of the sound leg the outer stick is level with the top of the great trochanter and the inner is about $1\frac{1}{2}$ in. below the perineum. The upper ends of the sticks are notched on the outer side so as to make them adhere in the plaster. Two small hooks are made of galvanized iron wire for insertion in the plaster. The patient lies upon a hard table with a sandbag under the buttocks and is made to press the stump backwards and inwards so that it is extended and adducted at the hip. A layer of stockinet is drawn up over the stump until it reaches above the tuberosity of the ischium posteriorly, to the perineum on the inner side and to the fold of the groin in front; at the end of the stump a circular pad of felt is applied and the stockinet is sewn over this. A plaster of Paris bandage is then applied to the stump, entirely enclosing it, reaching to within an inch of the perineum on the inner side, as high as the great trochanter on the outer side and up to or even above the tuberosity of

the ischium at the back. The bandage should not be applied too tightly, but must be well moulded upon the stump. When it has partly set, the wooden frame is fitted into place, care being taken that it lies parallel with the other limb. It is then fixed to the plaster bucket by applying additional bandages of plaster, and the two hooks are also included, on the inner



Fig. 10.—Plaster of Paris peg leg. The crutch stick is specially made, having a base block $2\frac{1}{2}$ inches wide.

and outer sides, about level with the lower end of the bucket. When the plaster has set the limb is removed and the plaster left to dry. The wooden crosspiece is then fixed below the bucket; this consists of a roller with a small groove upon which the chief sling can roll. The harness consists of a

broad waist-belt, buckling in front and supported by a sling which passes over the opposite shoulder. Three webbing bands are attached in front to the lower margin of the belt. The central one carries a buckle, the other two carry rings. A fourth band of webbing is fixed to the back of the belt ; this passes under the roller on the leg and is buckled to the middle band in front, the other two bands are attached to the hooks on the sides of the leg. These latter bands are interrupted by buckles so that they can be adjusted for length. In long stumps the mesial band and its hook can often be dispensed with. This band is not shown in the illustration.

A similar leg can be made for a below-knee amputation. The crutch sticks are fixed to a broader base block, 4 in. in diameter. They are cut so as to end just below the head of the tibia and fibula, and are incorporated in the plaster bucket in exactly the same way. No roller or hooks are used, but, instead, two loops of wire are inserted on either side of the bucket about two inches below the level of the joint. The harness consists of a broad band of webbing which laces around the thigh just above the knee ; from this are suspended four bands of webbing—two on the inner side, two on the outer side ; each of these passes through the appropriate loop in the bucket and is buckled to the thigh band. The reason for the use of two bands on either side is that if one is placed in front and one behind the knee centre, one or other is always tight whether the knee is extended or flexed, and the leg does not tend to fall off.

For a Syme's amputation an exactly similar leg is made, except that the end of the stump is allowed to rest upon the base block upon a felt pad, and the plaster case is only brought half-way down the calf ; if the whole calf is enclosed, the leg will not be removable because the end of the stump is bulbous.

Temporary limbs for the upper extremity have been very little used by the British ; they have, however, been made and fitted in considerable numbers by the Belgians and French. They are not required to produce shrinkage of the stump as there is not this difficulty in the upper limb. Their use is to induce the patient to use the stump to assist him in his daily life from the earliest moment, so that he may retain the movements in the remaining joints of the limb and the power of the muscles, and may not acquire the habit of relying completely upon his undamaged arm. For similar reasons apparatus for strengthening the muscles of the stump has been much advocated by the Belgians.

In the United Kingdom artificial arms were at first supplied hurriedly, the patients being fitted with them and discharged from hospital as soon as they gave evidence of ability to carry out very simple movements. The reason for this was that there were large numbers of men waiting to have their limbs fitted, but it was recognized that the method was not ideal. It was found, however, that few of these men realized the limitations of an artificial arm or understood that if they were to get any use out of it they must set to work themselves to learn its use and the ways in which they could adapt it to their own trade. Schools were then established at the limb fitting hospitals, in which the men could receive instruction in the use of their artificial arms. From this a great improvement in the utility of the arms immediately resulted. It may be laid down as a rule that every man to whom an artificial arm is given should be compelled to attend such a school until he has learnt to use it and until he has at least some idea how the arm can be adapted to the work of his own trade. Much of the pioneer work in arm instruction has been carried out by Captain Maxwell, the chief arm instructor to the Ministry of Pensions.

CHAPTER XV.

INJURIES AND AFFECTIONS OF THE EYE.

FOR the purpose of treating injuries and affections of the eye during the war an extensive specialist organization was gradually established. Military ophthalmic surgery in the British army during peace time was, for the most part, of necessity limited. For those ophthalmic officers who were stationed in Egypt or India there was great scope in both intra- and extra-ocular operations, but in the home service this was not the case.

In the home garrisons there were the sight-testing of recruits, the correction of presbyopia for certain of the clerical staff, and the treatment of minor ailments, such as corneal ulcer, ciliary blepharitis and the like, but these, together with the few cases of injury and of iritis, afforded the army ophthalmic specialists but little scope. Ocular operations were rare, for in selected, healthy young men, cataract, glaucoma and squints seldom occur.

On active service, however, and especially in a war such as that of 1914-1918, ample material was provided, both medical and surgical, for ophthalmic work and the ingenuity of ophthalmic specialists was taxed to the full, both in preserving and in restoring the best possible acuity of vision.

Not even in the districts of large steel works in England has there been in a given time such a wide experience in penetrating injuries as that which occurred at the chief operating ophthalmic centres in France, where on a busy day as many as 22 excisions of hopelessly lost eyes were performed, and some 25 cases with penetrating injury were put up to the large electro-magnet on the chance that a magnetic foreign body had entered the eye.

It was therefore of importance that the ophthalmic specialists in charge of such departments should be both highly experienced and skilled; on their judgment depended the saving or removal of eyes, and they had to decide the ever-recurring question whether an eye was "safe" or not from the point of view of sympathetic ophthalmia. They had to perform the highly specialized operations of removal of foreign bodies with the large and small magnets, and of trimming up wounds complicated with prolapse of uvea. These are admittedly some of the most difficult operations in ophthalmic surgery, and can

only be performed satisfactorily by those who have had full operative experience in ophthalmic hospitals. It is work quite beyond those who have merely passed an ophthalmic test after attending or working as clinical assistants for a few months at an ophthalmic clinic.

By the selection, as far as possible, of specialists who either held teaching ophthalmic posts in medical schools, or were surgeons on the staff of ophthalmic hospitals, or had held resident appointments as ophthalmic house surgeons, a team of special medical officers was obtained who directed and worked the various ophthalmic departments in a way which left little to be desired.

An immense saving of man-power was achieved by taking all acute cases with wounds or corneal ulcer, iritis, etc. into hospital and keeping them there till well on the way to recovery, after which their health was re-established by treatment at a convalescent hospital or *dépôt*, where they were all the time under specialist supervision. Patients got well at the maximum speed with the minimum of damage. This is a lesson it would be well to apply in civil practice.

The inclusion in the army of such vast numbers of men who in peace time were engaged on clerical and other close work, and depended upon glasses to correct their error of refraction necessitated large refraction departments. Owing to the efforts of the responsible officers of the Army Medical Department at the War Office, and Mr. J. H. Sutcliffe, of the British Optical Association, a magnificent organization for the supply of spectacles was developed, so that at the chief ophthalmic centres in France men who needed them received a free issue of spectacles, glazed with excellent lenses, spheres, cylinders or sphero-cylinders, in serviceable rust-proof frames, which had been fitted by trained opticians, together with a metal velvet-lined case, within a few minutes of their being ordered.

It is safe to say that, owing to the far-sighted policy of the War Office in supplying all modern equipment, men on active service within sound of the battle line have had the same skilled and scientific treatment as a city hospital could supply. They were treated till they were fit to return to duty or were evacuated to England. In the latter event they passed into the skilled hands of the ophthalmic surgeons at home.

The experience also of the effects on the eye of the gases used in warfare was unique, and is of such military importance, that the subject and the treatment call for special recognition in the history of the surgery of the war.

ORGANIZATION OF OPHTHALMIC DEPARTMENTS.

In the development of the ophthalmic organization the following were the chief steps:—

- (1) The setting up, first at the bases and later in each army, of separate departments for examining the ophthalmic out-patients.
- (2) The concentration in ophthalmic wards of the more severe eye cases, which needed in-patient treatment.
- (3) The organization for the treatment of the slighter eye cases at the convalescent depots in association with the general hospitals at the base.
- (4) The linking-up of the various centres by periodic visits of the supervising consultant.

Such organization as was finally reached started from modest beginnings. It was not until well on in November 1914 that tents or portions of existing buildings were set aside for the treatment of ophthalmic out-patient cases, placed under the charge of officers with ophthalmic knowledge, where men with minor ailments such as ciliary blepharitis, conjunctivitis, corneal ulcers, or errors of refraction, were treated. Tents were soon abandoned for the examination and testing of ophthalmic cases; they were neither light enough for external observation nor dark enough for retinoscopy or ophthalmoscopic examination. Later, in all the important bases, Boulogne, Rouen, Etaples, Calais and Le Havre, specially designed buildings were erected for ophthalmic out-patients, and equipped with every necessity; at Le Tréport the ophthalmic cases were seen either at No. 3 or at No. 16 General Hospital, in rooms adapted for the purpose.

The provision of ophthalmic wards, where injuries and severe eye cases could be under the daily and immediate supervision of the ophthalmic specialist and were attended by sisters trained in ophthalmic nursing, marked the second great advance. The improvement in the results showed the wisdom of this action; the skill acquired in dressing ophthalmic cases, washing out the eyes, applying ointments and drops, painting of lids, the organized system of hot bathings 4 to 6 times a day for severe cases of iritis, and the "tonic mental treatment" for the cases of functional blepharospasm, amblyopia, etc., were not and could not be obtained when these cases were scattered in different hospitals throughout a base.

To facilitate the concentration of ophthalmic cases red ophthalmic labels were attached to the men at the casualty clearing stations. When the ambulance train arrived at a

base station, the ophthalmic cases were easily separated by the Embarkation Medical Officer and sent, if possible, to the ophthalmic department. By such concentration a double advantage was gained; the cases received specialist treatment sooner, and a great deal of time and unnecessary labour was saved for the ophthalmic specialist who, previous to such concentration, had not only to carry out all the treatment in the ophthalmic out-patient department, but to visit the various hospitals, seek out the cases, operate on those who required operation, and visit them until they were evacuated to England, or were fit for duty.

The ophthalmic centres were always part of a general hospital, with the consequent very great advantage that eye cases complicated with other injuries or diseases could be treated by and be under the constant supervision of general surgeons or physicians, in addition to the ophthalmic specialist.

Convalescent Dépôts.—The institution of convalescent dépôts in association with base hospitals proved as great an advantage to ophthalmic as to general cases. As soon as a man was fit to be discharged from the ophthalmic wards, he was transferred to the convalescent dépôt where his treatment was continued until he was fit to return to duty. It is difficult to exaggerate the importance of the continuous ophthalmic supervision thus afforded; the man not only received the special treatment which he required, but in addition he shared the healthy discipline and recreation afforded by life at the dépôt. Cures were effected in a surprisingly short space of time, and the return of these men to duty was thus considerably expedited. Their condition improved a great deal more rapidly than if they had been sent home, where almost invariably they were kept in hospital all the time.

When the camp was situated some distance away from the ophthalmic department daily visits for every case were impracticable and the minor treatments, such as washing the eye, painting the conjunctiva, or applying ointment to the lid margins, were carried out at the camp by orderlies trained in ophthalmic technique and the patient was sent periodically to the department. But when the camp was immediately adjacent to the ophthalmic department, as at Rouen, all treatment was carried out in the department itself with obvious advantages.

Consulting Ophthalmic Surgeon.—The consulting ophthalmic surgeon appointed to direct and supervise the work in the various ophthalmic centres could always be called to see any

ophthalmic case at any hospital, whether at the base or the front, on application to the administrative authorities. In the early days there was difficulty in allowing him to visit the various centres unless he was specially sent for. This limited his usefulness, for often he was requested to come merely to confirm the advice that a hopelessly lost eye should be removed. Though this was of importance, much more good could be done by the consultant visiting regularly and supervising the treatment of cases for whom he would not be specially sent. This was recognized later and full scope in visiting was permitted. By these regular visits the greater experience of the consultant was made available, information concerning new methods of treatment and rare cases was circularized, interest was stimulated and the capacity of and results obtained by the various specialists were gauged. In addition, the special wants of each centre were recognized, requirements applied for and obtained and the whole work was standardized at a higher level.

Base Ophthalmic Centres.—A base ophthalmic centre consisted of :—

- (1) Out-patient department.
- (2) In-patient department—including wards and operating theatre.

The out-patient section consisted of waiting room, consulting room and opticians' department. The various consulting rooms were designed on much the same plan and differed only in detail; as a rule they were specially built and arranged to save both space and time, so that the external examination, the testing of sight and dark room examination could be carried out in the same room. The consulting room at Boulogne may be described as a type (Fig. 1). It was 22 ft. long by 18 ft. wide and was provided with two windows, one on each side. The entrance was at one end and opposite this was a row of three cubicles, each fitted with an ophthalmoscopic lamp and a complete set of lenses, spherical and cylindrical. These cubicles could be shut off and darkened from the rest of the room by curtains, and opposite them at the other end of the room over the door the box test-types were fixed against the wall. The patient in the cubicle sat about 1 ft. from the wall and as the box test-type projected also about 1 ft. the required distance of 20 ft. between the two was attained. At one corner of the room were a table and chairs where minor treatments could be carried out. In some centres where the

accommodation was larger, these minor treatments were carried out in a separate hut, which had obvious advantages.

The external examination was made at a desk placed opposite one of the windows whence the patient was sent either to the treatment corner of the room to have his lids painted, cysts removed, eyes bathed, etc., or if he required his sight to be tested to one of the cubicles. Here his sight was recorded and on closing the curtains retinoscopy was performed and the fundus examined, while on opening the curtains his sight could be tested with the appropriate glasses and he was then handed over to the opticians' department where he was fitted

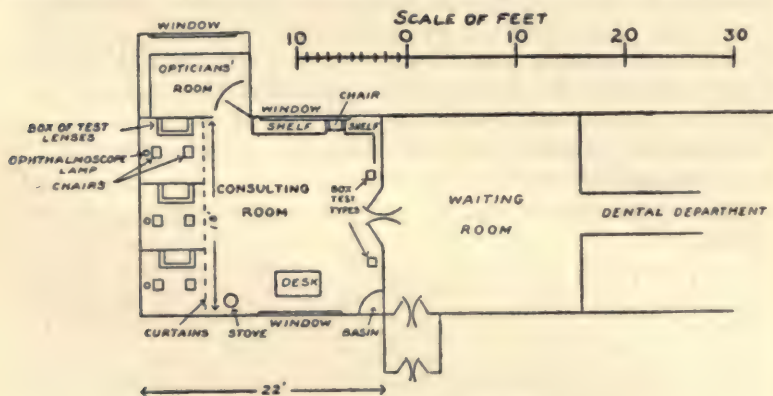


Fig. 1.—Consulting room at Boulogne.

with spectacles. This arrangement of the consulting room effected a great saving of time in examination and expense in construction.

The in-patients were treated in special wards under the immediate care of the ophthalmic specialists and trained nurses. As already mentioned, the special care thus obtained proved of immense value; the intraocular operation cases received the delicate manipulative treatment that was necessary and the hot bathings, the frequent irrigation of the conjunctival sac, the painting of the lids, etc., were all carried out in a skilled way which was practically impossible in a general ward.

In busy times the number of ophthalmic operations was so great as gravely to obstruct the work of the operating theatres for general cases, and it was found advisable therefore in some of the larger centres to have a special operating theatre in which was placed the large electro-magnet.

Large electro-magnets for the removal of magnetic foreign bodies were supplied at Boulogne, Rouen and Etaples, which were known as "magnet centres" to which, if it was suspected that a foreign body had entered the eye, urgent cases could be sent direct from the casualty clearing station.

The number of ophthalmic beds varied at different centres according to requirements; thus at Boulogne and Rouen there were from 120 to 170 beds.

At Boulogne there was a ward for 12 officers in a special block built by the Joint Committee of the British Red Cross Society and Order of St. John in the same hospital as the ophthalmic department. This officers' ward was a great boon; it not only afforded constant supervision of the cases by ophthalmic specialists and trained sisters, but the amount of visiting by the specialist at other hospitals was diminished, and the care of the officer "magnet cases" was greatly simplified. Previous to its existence such cases were at a disadvantage as compared with other ranks; for the officer had to be brought from his hospital to the ophthalmic department to be put up to the magnet, and if no operation was performed he had to be sent back again, a fatiguing process involving definite risks, while if a foreign body was removed, the officer had to be housed in the men's ward for the three or four days until the wound had become sealed.

Most of the cases with severe eye injuries arriving at a base were concentrated in the ophthalmic wards, but when, through stress of work, complete separation of cases on arrival was impossible, or when a man had other injuries in addition to an ophthalmic wound, or when the eye condition was found out only on arrival, it was unavoidable that a certain number of cases were distributed among other hospitals. As soon as they were discovered, the ophthalmic specialist was notified and they were visited and either transferred or treated where they were, as the nature of the case indicated.

With the huge influx of "gassed cases," accommodation in ophthalmic wards for all those with their eyes thus affected was, of course, impossible; the worst cases were visited regularly by the specialist, and the few that needed operation were transferred.

An ophthalmic pathological department was also built by the Joint Committee of the British Red Cross Society and Order of St. John for the centre at Boulogne, where the examination of several hundred blinded eyes that had been removed was carried out, from which an interesting series of pathological

specimens now in the War Office Collection was made. With the help of a trained laboratory assistant, valuable microscopic sections were obtained of a large number of rare cases of concussion, etc., and in this laboratory also a series of stereoscopic photographs and also microphotographs were taken which are of considerable interest.

The services of a highly skilled artist, Sergeant A. K. Maxwell, R.A.M.C., were obtained through the Medical Research Committee. In addition to his well-known series of drawings of general medical and surgical importance, he made a number of valuable and beautiful studies of ophthalmoscopic changes of unique interest, as well as of many external ocular conditions.

Army Ophthalmic Centres.—Early in 1915 it was recognized by the medical authorities that a great waste of time was caused by men at the front, who went sick on account of their eyes, being sent to the base for treatment. Directly a man passed from his army area to the lines of communication, it was a matter of routine for him, as soon as he was fit for duty, to pass to the base depot of his unit before he could rejoin his battalion, and in this way many weeks or even months might elapse before he got back to the line.

Major Riach, R.A.M.C., was consequently posted to St. Omer, where he started an advanced ophthalmic centre to which ophthalmic cases were sent from the various armies. He organized an excellent system by which groups of men were sent to this centre from different divisions on stated days. They arrived by motor transport on one day, were treated, and were sent back to duty on the following day. In this way great saving of time was effected, and "touring the bases" by ophthalmic cases was in great measure prevented. The work at this advanced centre was so successful that in time an ophthalmic centre in the charge of an ophthalmic specialist was created for each army, and located at one of the casualty clearing stations in the army area concerned.

The ophthalmic specialist at an army ophthalmic centre not only looked after the ophthalmic sick who were sent to him in batches in regular order from the various units, but he saw and treated all the ophthalmic battle casualties which came through the casualty clearing station to which he was attached. In addition he might be asked to visit any other casualty clearing station in the army, to examine and treat any eye patient who was too ill to be moved at once to the base.

It was impossible to retain the eye cases in the wards of the

casualty clearing stations throughout their convalescence, for as many beds as possible had to be kept empty in case of any sudden influx of wounded. These cases were therefore drafted to a base ophthalmic centre or to England at the earliest possible date.

Staff of Ophthalmic Centres.—The staff of an ophthalmic centre consisted of the ophthalmic specialist or specialists, nurses, orderlies and one or more opticians. The centre was always attached either to a general or stationary hospital or to a casualty clearing station, but it was self-contained, the ophthalmic work being separate from that done in the other part of the hospital. The staff, however, was never put on a separate establishment, but was borne on the establishment of the hospital to which it was attached. This arrangement had certain disadvantages, for a senior ophthalmic specialist, who on the grounds of valuable service or seniority might be entitled to the rank of major, could not obtain this without taking the rank which would otherwise have been held by an officer of the hospital performing general duty. The same difficulty occurred with the opticians and orderlies, many of whom were highly skilled, but to whom no rise in rank with pay and allowances could be given without sacrificing the non-commissioned ranks of others on the establishment of the hospital.

Evacuation of Ophthalmic Sick.

Ophthalmic battle casualties were sent to the nearest casualty clearing station and from there were evacuated by train to a base ophthalmic centre or to the United Kingdom.

Urgent cases with a foreign body in the eye were frequently sent to a base magnet centre direct by ambulance car from the casualty clearing station, but when a patient was too ill to be moved at once, the consulting ophthalmic surgeon or the ophthalmic specialist of the army concerned could be sent for to visit and treat him until he was fit for evacuation. Those with minor ailments were sent to and treated at the ophthalmic centres belonging to the army or, if requiring prolonged treatment, were sent to the base.

The base ophthalmic centres received men sent from the casualty clearing stations, and thus treated the bulk of the severe cases requiring operation; they also treated the local ophthalmic sick of the corresponding base. Their cases were evacuated either to the United Kingdom or to convalescent depots.

A portion of the cases evacuated to England were labelled for certain hospitals.

- (a) Those who were blinded in both eyes were sent to No. 2 London General Hospital, St. Mark's, Chelsea. Here they were tended until no further surgical treatment was required, and were then sent on to the special training centre for blinded soldiers, St. Dunstan's.
- (b) Certain cases of severely wounded eyes which needed skilled care were labelled for ophthalmic hospitals, or ophthalmic departments of general hospitals.
- (c) The remainder, by far the larger number of ophthalmic cases, did not necessarily come under specialist supervision. This had obvious disadvantages. Some did not get the skilled aid they required, but perhaps the most serious drawback was that of delayed return to duty; for a great number of men who became fit for duty were not sent back as soon as they might have been. This was especially so in the case of "gassed eyes."

It was unfortunately not until near the close of the war when Colonel Parsons had been appointed consulting ophthalmic surgeon to the forces, that a complete scheme was planned for the ophthalmic cases in the United Kingdom.

Under this scheme each command in the British Isles had a deputy ophthalmic consultant who worked under the direction of the consulting ophthalmic surgeon to the forces. He was responsible for the supervision of eye cases in the various ophthalmic centres of that command, and not only visited regularly these centres, but could be called in at any time to see urgent cases. Each ophthalmic centre was under the care of one or more ophthalmic specialists, and to it were affiliated certain convalescent depots in which there were ophthalmic departments, also under the care of an ophthalmic specialist.

On their arrival in England, all ophthalmic cases were to be sent to an ophthalmic centre. As soon as they were ready for convalescent treatment they were to be sent to one of the convalescent depots affiliated to the ophthalmic centre.

By such a scheme skilled treatment was assured and wastage greatly lessened.

Supply of Spectacles.

The advisability of supplying glasses to the fighting soldier has long been a debated subject. A recruiting ideal would be only to enlist men who have perfect acuity of vision and

no error of refraction; men who would be independent of glasses until presbyopia overtook them, by which time they would be for the most part out of active service.

The necessity for glasses is an evil both for the fighting man and the authorities who may be responsible for their supply. On the one hand spectacles get lost or broken, especially in trench life, where during wet weather it is practically impossible to keep them clean. On the other hand, the supply and replacement of glasses is a very complicated and costly matter. Unfortunately the number of recruits with normal vision is inadequate even in peace time to keep the army up to strength, and therefore still more so in time of war.

Prior to the war the authorities adopted a standard which was intended to ensure moderate but adequate vision without glasses, leaving the man to get spectacles or not as he liked. In this way it was thought that such an army could be sent to any part of the world and be independent of the supply of glasses. Such a plan worked moderately well, though many men then enlisted must have needed glasses on active service, and could not get them then.

Under the stress of the war recruiting was carried out on so large a scale that even that standard of vision could not be maintained. Men were often either scantily tested, or in their anxiety to be recruited avoided the tests, so that great numbers were enlisted who were not up to army standard and required glasses to make them efficient. There was also amongst those enlisted a very high proportion who in civil life had become dependent on glasses and were at a loss without them; again, during the war, many men who previously had not felt the need of glasses suffered from asthenopia and went sick with headache and nerve strain.

There are no complete records of the number of men who attended the refraction departments during the whole war, but it was obviously very great. An interesting proportional record was collected in France for the twelve months beginning 1st May, 1915, and ending 30th April, 1916. During this period the army in France had not reached its maximum strength and the army ophthalmic centres were not completely developed, so that later in the war the numbers over a similar period would have been greatly increased. In the twelve months, 23,809 men attended the refraction departments to have their sight tested, of whom 8,972 were returned to duty as "fit without glasses"; 4,396 were ordered spheres,

of whom 4,057 were returned "fit for duty with glasses"; 4,966 were ordered cylinders or sphero-cylinders, of whom 4,405 were returned "fit for duty with glasses." The remaining 5,475 were either transferred to other bases or not helped by glasses, or were unaccounted for.

It gradually became recognized by the army authorities that an organized supply of glasses for the soldier was an absolute necessity.

A certain number of the dissatisfied or those worn out with fatigue, when they know there is an ophthalmic department to attend, may unnecessarily go sick on account of the eyes, or break or throw away glasses in order to get a few days' respite from the stress of work, but the trouble this causes is no strong argument against having refraction departments, while apart from the fighting officers and men, very large numbers of individuals doing clerical work were greatly handicapped if they could not get glasses.

A properly run refraction department is a great asset to the army in preserving both the power and good temper of the fighting officer and man. Those who really need glasses will wear them readily enough and be much fitter men for doing so; those who are told they do not require them realize that they have been properly examined, and for the most part are satisfied at being reassured that their sight is good. The few who remain discontented have no just cause for complaint.

In the early days of the war those who came to be tested at the ophthalmic centres and needed glasses bought them from local opticians, a system which worked unsatisfactorily, especially abroad, for there was great delay in their supply, and men had frequently to pay comparatively large sums for indifferent material.

In the spring of 1915, the War Office issued to ophthalmic centres supplies of oval convex and concave spherical lenses with sets of corresponding frames, the lenses being interchangeable. The spectacles were made up by the ophthalmic specialists and orderlies, who had to select from the limited supply at their disposal such frames as best met the individual variations in the interpupillary distance, the height and projection of bridge. They also had to make such adjustments as "angling" of the frame. Some became fairly proficient, but few were very expert, and the fitting was often extremely rough. No cylinders or sphero-cylinders were issued free of cost, and in consequence those who required an astigmatic correction had to buy their glasses and pay heavily for them.

The men never understood this illogical scheme which supplied a free issue of glasses to some and not to others.

In November 1915, the War Office decided to make a free issue of glasses, both spheres and cylinders, to those soldiers who required spectacles, and an Army Spectacle Depot was organized. It was formed at Cliffords Inn Hall, Fleet Street, under Mr. J. H. Sutcliffe, of the British Optical Association, and was the distributing centre for all the glasses required by the army ophthalmic centres, both at home and abroad. It will be appreciated on what a large scale and how carefully the organization had to be run, when it is known that there were 98 ophthalmic centres in the British Isles, including six Canadian, three Australian and three New Zealand centres; twelve in France, five in Egypt, three in Italy, three in Salonika, one centre each at Malta, Gibraltar, Bermuda, Baghdad and Sierra Leone, and five U.S.A. centres, all of them supplied from the Army Spectacle Depot in London.

At this depot vast supplies of lenses, frames and spectacle cases of standard pattern were collected and stocked, and, in addition, a considerable number of exceptional lenses was ground and special frames made.

To this depot were sent all prescriptions for glasses, which were ordered at the various ophthalmic centres in England, and it was here that all these spectacles were made up and despatched in steel cases, velvet lined, within 24 hours of the receipt of the prescription.

For the troops abroad consignments of frames, lenses and cases were sent out to the various ophthalmic centres overseas.

Besides the ordinary spectacles, several special sorts were supplied for particular purposes, such as tinted glasses for those in Egypt and Palestine, and triplex glasses, either plain or worked to a prescription, for officers in the Flying Corps.

All ophthalmic necessities, such as sets of trial lenses, boxes of the 48 specimen frames, ophthalmoscope lamp brackets, test types, tools, grindstones, etc., were supplied to the different centres, while later on in the war artificial eyes were stocked, and batches of assorted eyes were sent out. A certain number of those required of a peculiar shape was also made at the Army Spectacle Depot.

At home centres no stocks of lenses were kept, but the spectacles, as already mentioned, were made up at the Army Spectacle Depot. The prescription was made out in duplicate, one copy was kept at the ophthalmic centre and filed and the other sent to the Army Spectacle Depot. As soon as the

spectacles were made they were posted to the centre with the prescription ; the spectacles were sent to the man and the prescription, after being receipted, was returned to the Army Spectacle Depot and filed. By this means a filed record for reference was kept both at the centre and at the Army Spectacle Depot of every pair of glasses ordered.

At centres overseas, in order to avoid the great delay in obtaining spectacles, which must have occurred if prescriptions could only be made up in London, a supply of lenses and frames was kept, and one or more opticians stationed at the centre to carry out the making up of the spectacles. In spite of the enormous stock of lenses collected it was found impossible to supply each centre with a complete set of cylindrical and sphero-cylindrical lenses. It was arranged, therefore, that while each centre had complete stocks of spherical lenses and frames, at the larger and more important centres only was there a stock of cylindrical and sphero-cylindrical lenses. The smaller centres sent their prescriptions for astigmatic glasses to the larger centres where they were made up and posted back.

The frames were of non-rustable white metal with curved sides of twisted wire ; the pattern selected combined excellent durability with sufficient lightness. All the frames had the same sized "round eyes," 36.5 mm. in diameter, so that the lenses were interchangeable, and cylindrical lenses could be adjusted to any desired axis.

Forty-eight different stock sizes, each of which had a distinctive letter, were kept for the variations in interpupillary distance, height and projection of bridge, as shown in the following table :—

Sizes and Lettering of Frames kept in Stock.

Bridge Height.			mm. Projection.	Centres 57 mm.	Centres 60 mm.	Centres 63 mm.	Centres 66 mm.
Level	..	..	3 in	A.A.	A.	N.	N.N.
Level	..	..	Flush	B.B.	B.	O.	O.O.
3 up	..	..	3 in	C.C.	C.	P.	P.P.
3 up	..	..	Flush	D.D.	D.	Q.	Q.Q.
3 up	..	..	3 out	E.E.	E.	R.	R.R.
6 up	..	..	Flush	F.F.	F.	S.	S.S.
6 up	..	..	3 out	H.H.	H.	T.	T.T.
Level	..	..	3 out	J.J.	J.	U.	U.U.
6 up	..	..	6 out	K.K.	K.	W.	W.W.
9 up	..	..	3 out	L.L.	L.	Y.	Y.Y.
9 up	..	..	6 out	M.M.	M.	Z.	Z.Z.
6 up	..	..	3 in	G.G.	G.	X.	X.X.

The instructions for the measurement of the round-eye frame supplied by the Army Spectacle Depot were as follows:—

Pupillary distance.—Measure from the inside of one wire at side-joint to a point on the inside of other eye wire at bridge-joint.

Height of bridge.—Measure from a line drawn through the horizontal centre of the frame through both side-joints to the lower edge of the bridge crest.

Projection of bridge.—Measure from the back plane of eye wires of frame to the upper edge of crest of bridge.

Measurements.—Invariably proceed by degrees of three millimetres only. The fitting sets consist of 16 frames, 11 of which are specimens of the bridge heights and projections in a 60 millimetre pupillary distance, and five are similar specimens, but in varying pupillary distances.

Examples.—Frame Mark "A" is 60 mm. pupillary distance, level in height, and 3 mm. inset projection; if a similar bridge is required in 63 mm. centres, give Mark "N" frame; if 66 mm., give "N.N."; if 57 mm., give "A.A."

The specimen frames should be kept well oiled and carefully in shape to the above system of measurements, and should not be altered in any way. Any deviation from the above measurements, such as intermediate centering or alteration of bridge, must be made locally by the optician. A round-eye frame generally requires a higher bridge than an oval-eye frame in order to clear the eyebrows.

The lenses cut and ground were stocked ready to fit the standard round-eye frames. Grooved "fillings" and grind-stones were supplied to the ophthalmic centres so that if the lenses were a trifle too small, a tight fit could be made by using the filling, or if they were too large they could be ground to the right size.

In order to retain cylinders at the right axes, the lenses were fixed into frames by means of amalgam or cement. A refinement carried out at the Army Spectacle Depot was the punching of the frames at the line of axis and the cutting of a notch in the lens to correspond, which fixed the cylinder perfectly at the appropriate angle.

In the early days of the issue of spectacles the strength of the lenses supplied was restricted, but as the need for men became greater and the sight tests were lowered, it was found advisable to issue practically any glasses which could make men efficient, and the following instructions were issued accordingly to the staff of the Army Spectacle Depot.

- (a) No simple spherical lens will be supplied of a less strength than 1·00 dioptré, or of a greater strength than 18·00 dioptries.
- (b) No simple cylindrical lens will be supplied of a less strength than 0·50 dioptré, or of a greater strength than 6·00 dioptries.
- (c) No sphero-cylindrical lens will be supplied having before or after transposition :—
 - (i) One of its component parts less than 0·50 dioptré, and the other component part less than 1·00 dioptré.
 - (ii) A combined strength greater than 18·00 dioptries, or
 - (iii) A cylindrical strength greater than 6·00 dioptries.
- (d) No sphero-cylindrical lens will be supplied having a concave spherical surface with a convex cylindrical surface.

(e) No quarter-dioptre lenses will be supplied above 3·00 dioptres, and no half-dioptre lenses above 6·00 dioptres.

No man is accepted for any military service where the visual acuity, with or without glasses, is less than 6/60 in one eye, that of the other being less or nil.

Prescriptions were made out on a special form.*

Owing to the frequent breakage and loss of spectacles and to the fact that the man soon lost touch with the centre where the glasses were ordered, a great deal of labour was incurred in retesting. To avoid this a small prescription label was pasted into each man's pay book giving full details of both lenses and "letter" of frame, and the man's vision, both without and with glasses. By stamping the name of the centre in indelible ink, partly on the label and partly on the pay book, a man was deterred from removing the label from his pay book, for if he did so, an indication was given that this had been done. (Fig. 2.)

NO. & RANK NAME CORPS					DATE OF EXAM :	
					DATE OF ISSUE :	
R	VISION W'OUT GLS	SPH	CYL	AXIS STANDARD NOTATION	VISION WITH GLS	OPHTH. CENTRE :
						FRAME NO : (OR MEASUREMENTS)
L						
SIGNATURE } OF M.O. }					OPTICIAN'S INITIALS	

Fig. 2.—Pay book prescription form.

INJURIES AND AFFECTIONS OF THE EYE ON THE WESTERN FRONT.

The different types of eye injuries and affections met with on the Western front during the war may be considered under five different headings :—concussion injuries ; wounds ; functional disorders ; certain affections due to diseases ; and injuries due to gas warfare.

Concussion Injuries.

Cases of concussion were very numerous, as would be expected and as in civil life presented a large number of types.

Ruptures of the Sclerotic.—These were common, and in addition

* Army Spectacle Depot form No. 96.

to those concentric with the margin of the cornea, such as are seen in civil practice, there were found :—

- (1) Explosive ruptures caused by a foreign body which had passed through the eye splitting the sclerotic in all directions.
- (2) Ruptures caused by missiles passing through the orbit without directly hitting the eye, the rupture being on the side of the globe opposite the point of impact, *e.g.*—
 - (i) A missile through the outer side of the orbit caused a large equatorial rupture on the inner side.
 - (ii) Missiles traversing the back of the orbit caused ruptures of the cornea and the anterior part of the sclerotic.

Injuries of the Iris and Ciliary body.—Rare cases of retroflexion of the iris and cyclodialysis—both partial and complete—were seen, in addition to the common conditions such as irido-dialysis and rupture of the sphincter.

Affection of the Lens.—A large number of cases of the peculiar opacity in the lens known as “Vossius ring” were seen, as well as other forms of concussion cataract.

Hæmorrhages in the Eye.—All types were met with: hyphæma, hæmorrhages into the vitreous, retina and choroid, as well as subhyaloid, subretinal and subchoroidal hæmorrhages. In one case, hæmorrhage was found within the capsule of the lens.

Injuries of the Retina and Choroid.—The characteristic concussion change in the retina and choroid as seen with the ophthalmoscope was one of the most dramatic pictures this instrument reveals; namely, large areas of dark red hæmorrhage interspersed with glistening white areas. These changes followed the passage of a missile through the orbit and always occurred on the side of impact, often also at the macula and occasionally on the opposite side of the eye.

From examination of microscopic sections of concussed retina it seems probable that the white areas are due to a necrotic change in the retina, the hæmorrhages being derived from both retinal and choroidal vessels.

“Holes at the macula” and in other parts of the retina were met with, but a smaller proportion was seen than would have been anticipated from experience of concussion cases in civil practice.

Ruptures of the choroid were common, not only of the usual type concentric with the disc, but also those disposed radially from the disc.

Evulsion of the Optic Nerve.—This condition, which is very rare in civil life, was met with on several occasions.

Concussion was produced in certain instances in surprising ways; comparatively large missiles at the end of their flight lodged in or about the orbit. In one instance a piece of metal 4 in. by 3 in. was removed from the side of the face and orbit. Several bullets were found embedded in the orbit. In one instance a whole shrapnel ball was found lodged between the lower lid and the globe without rupture of the eye; that it was not placed there by the patient himself was proved by the severe concussion changes in the eye; at the end of its flight it must have fallen against the eye pushing it backwards and dropping into the lower fornix.

The concussion changes in the eye indicated the exact track of the missile, and thus ophthalmoscopic examination gave valuable assistance to the general surgeon.

"Windage."—Amongst the concussion cases no single case was met with where visible defect of the retina, choroid or nerve was due to "windage" in the ordinarily accepted sense of the term, following the explosion of a shell in the immediate vicinity. In every case where there was ophthalmoscopic change, definite evidence was found either that the eye had been struck directly, or that a missile had passed through the orbit. In certain instances it would have been easy to account for the condition as due to "windage"; for in some it was only after very careful search that minute scars were found showing that a small particle had passed through the eye; or in others, after an X-ray photograph had been taken, it was recognized that a foreign body had passed through or lodged in the orbit from behind or from the opposite side of the face.

Thus, in one instance, an eye was found to be quite blind, but showed no visible external defect or sign of injury. On ophthalmoscopic examination there was no light reflex; it was then discovered that there was one minute scar in the temple and another on the opposite side of the nose, indicating a through-and-through wound, caused by a foreign body so small that it did not cause a rupture of the eye, but with so great a velocity that it had sufficient momentum to pass through the bones of the temple, the orbit, the eye, the nose and the hard nasal bone on the opposite side. Excision of this blind shrinking eye proved the existence of a through-and-through wound. In another case an eye was blind with severe concussion changes in the fundus, but there was no

visible disturbance of the orbit, no proptosis, no subconjunctival hæmorrhage or ecchymosis of the lids, and no limitation of the movement of the eye. The X-ray photograph revealed that a large fragment of shell-case had passed into the back of the orbit through the cranial cavity. Again evulsion of the optic nerve on one side with no apparent disturbance of the orbit was caused by a small fragment of metal which had penetrated from the opposite side of the face.

Such being the experience, the numerous cases spoken of and published in which neuritis, retinitis, rupture of the choroid, etc., and even evulsion of the globe, were described as due to "windage" or the "suction of a passing bullet," were looked upon by the British ophthalmic specialists in France with considerable suspicion.

Many cases of concussion must have occurred where there was no history or external sign of injury. If a man were "blown up" an eye might receive a severe blow from a stone or clod of earth of which the man either knew or remembered nothing. No external signs might be visible a few days after, and yet the eye might show ophthalmoscopic signs of concussion. Such cases might easily have been thought to be due to concussion by air.

One true case of "windage" was seen where a bullet had traversed the bridge of the nose horizontally and passed between the lids of the eye on the side of the face opposite to its entry, excoriating the margin of the upper lid, but without abrading the cornea. Opposite the excoriation of the lid the cornea was grey and infiltrated and showed posterior striate keratitis, and the iris opposite the grey spot in the cornea would not dilate with atropin for over a week. Gradually the corneal haze cleared, the pupil became circular, and the vision was restored unaffected. This case was reasonably looked on as one where the eye was concussed by the cushion of air reflected from a passing bullet.

Wounds and Intra-ocular Foreign Bodies.

As would be expected, a great number of cases came under observation in which the eye had been perforated by flying fragments, and in the majority of cases that lent themselves to conservative treatment the condition was complicated by the retention of a foreign body either in the coats of the eye or actually within the eye itself. Simple perforating wounds caused by an object that fell or, as in the case of a bayonet wound, was withdrawn from the eye were much less common.

The consideration, therefore, of penetrating wounds of the eye necessarily involves an account of the numerous cases in which a foreign body was retained within the eye and the measures that were taken to deal with them.

Injuries with bayonets were rare ; they were nearly always accidental and not of enemy origin. Provided the injury was not very severe the results obtained by treatment were much the same as those seen in civil life in cases of simple perforating wounds ; for example, in one case in which the cornea was perforated below, the iris was prolapsed, but the lens uninjured ; an iridectomy, performed so as to free the wound of uvea, left the eye with full vision.

The variety of foreign bodies encountered forms quite a long list and, from the method that was adopted to deal with them, may best be classified as magnetic and non-magnetic.

Among magnetic bodies may be mentioned portions of the cast-iron cases of shrapnel or high explosive shells and the ferro-nickel casing of German rifle and machine-gun bullets, and, as would be expected, the latter were much less magnetic than the former. The cupro-nickel of British bullets was non-magnetic.

Among non-magnetic foreign bodies were pieces of wood, stone, copper, nickel, aluminium, brass, lead, pieces of the casing of British bullets and particles of cordite. A few cases were seen in which small dust-like particles of trinitrotoluol had entered the eye, causing the iris to be covered with golden coloured crystals.

Foreign bodies retained within the coats of the eye without perforation.—The commonest cases were those in which the cornea had been spattered with particles of sand ; in some there were actually hundreds of grains, some superficial and some so deep that it was difficult to decide whether a particle had or had not actually perforated the cornea, or had come to lie so that it was partly within the anterior chamber. The superficial fragments were easily removed, but it was impossible to rid the cornea of all the particles at one sitting, as the surface necessarily became so roughened that the deeper particles became invisible. When deeply placed a foreign body was best removed by following up the track of entrance with a sharp stiff instrument such as a Græfe or Beer's knife cutting gently through the corneal tissue over-lying the particle and working with the aid of a magnifying glass. When the foreign bodies were not causing any irritation it was found better to leave the deeper ones alone, since interference

brought about more opacity; but when the eye remained irritable it was generally wiser to remove them, though if left alone the eye usually became quiet but only after prolonged convalescence.

On several occasions small pieces of cordite were found; these appeared as small polygonal flakes, yellowish in colour, and they caused great irritation until removed.

In those instances in which embedded foreign bodies were removed, it was rare to meet with septic complications, though, when numerous, the scars left by the foreign bodies caused considerable damage to sight. In a few cases of these spattered corneæ the whole surface became yellow and infiltrated from secondary infection, and severe nebulization resulted.

Similar fragments were often found in the conjunctiva; they were well tolerated and caused little trouble. If they caused irritation some were removed with a needle, but those which were subconjunctival had often to be removed with the over-lying tissue, a stitch being used to repair the wound.

Penetrating wounds of the eye with or without the retention of a foreign body.—The evidence of perforation was often quite clear, the wound could be seen either in the cornea or sclera, but in some instances the scar in the cornea was so minute that it was difficult to detect, or if in the sclera it might be obscured by a subconjunctival hæmorrhage. In a good number penetration took place behind the conjunctival reflection and there was no external wound of the eye. It was in these cases that a perforation was easily overlooked.

The special points to be looked for were punctured wounds of the lids, loss of tension, abnormal depth of the anterior chamber, a hole in the iris, an opaque track through the lens, hæmorrhage into the vitreous, while in those cases in which the vitreous was sufficiently clear a wound of the choroid and retina might sometimes be observed with the ophthalmoscope and sometimes the foreign body itself might be seen in the vitreous or lying on the retina.

In every case of penetration there was some loss of acuity of vision, and though this might be due to concussion without penetration, it was such a suspicious sign of penetration that it was found advisable to put up to the magnet practically all eyes which had been injured and in which there was loss of acuity. It was surprising how many eyes were thus proved to contain a foreign body, even when after careful examination such a condition was thought to be quite unlikely.

The importance of a very complete examination of any case of a wound in the neighbourhood of the eye will be shown by the following examples. A soldier presented himself with very defective vision in an eye that to external examination appeared quite uninjured. Upon ophthalmoscopic examination blood was found in the vitreous, no red reflex was to be seen, and the eye was quite blind. Upon careful examination a minute perforation was found in the lid showing that a small fragment had entered the eye behind the conjunctival fornix and had passed right through the eye and come to rest in the orbit, as was proved by X-ray examination. Again cases were met with in which the fragment having perforated the eye in this manner had passed through the nasal cavity and so come to lie in the opposite orbit or eye, causing in this way blindness of both eyes. Other cases were seen in which the foreign body had entered the eye by way of the cranial cavity. In one such case the cornea was ruptured and the eye collapsed; when the eye was removed no foreign body was found either in the eye or orbit in spite of there being a wound in the posterior part of the eye. An X-ray examination was also negative, no sign of a fragment being found either in the orbit or cranial cavity. The patient died of meningitis, and it was not until the post-mortem examination that a small wound through which a minute piece of shrapnel had entered the skull was found in the scalp over the occiput and a track admitting a probe was seen which proved that the foreign body had passed through the occipital bone, cerebellum, apex of the petrous bone and so into the orbit and out through the eye. In another case there was a small wound of the upper lid at its upper and inner part; there was no defect of vision and nothing abnormal could be found by ophthalmoscopic examination. This man died of meningitis five days after being wounded. At the post-mortem examination the wound was found to have been caused by a piece of shrapnel no larger than a lentil which had pierced the cribriform plate of the skull and lodged just within the cranial cavity. Such cases illustrate the minute search that was often necessary in order to determine the path followed by a foreign body in reaching the eye, orbit or brain.

In the majority of cases the injury was made by quite small particles; there were, however, cases in which the fragment causing the injury was very large; enormous pieces of shell casing were removed from the orbit when, of course, the eye ball was ruptured and at times rendered unrecognizable. The small fragments which, after piercing the coats of the eye,

came to rest within it were unlike those met with in industrial life ; these are usually small, smooth, and oat-shaped, and the damage done by them is comparatively slight. In war injuries on the other hand, the pieces were on the whole larger and much more irregular in shape, being twisted or having very sharp angles. The damage done by the actual perforation was, therefore, much more severe, the wounds larger, and the laceration of the uvea correspondingly more serious. Again, in industrial life the fragments are often sterile. In war wounds the foreign bodies were frequently not sterile, and in those cases much of the trouble in removal was due to a low form of sepsis which did not actually end in suppuration but which caused the deposit of sticky lymph around the foreign body.

The wounds in the cornea varied in size from a minute perforation to an extensive gaping wound with or without prolapse of the uvea. The large wounds naturally did not admit of conservative treatment but a number of the smaller wounds healed remarkably well. Wounds of the iris were often mere punctures, and through the dilated pupil a track of opacity could sometimes be seen in the lens, indicating that a foreign body had traversed both iris and lens. Tracks in the vitreous were sometimes seen when several days had elapsed since the injury ; these were due to a mild infection causing inflammatory products to be deposited, or to a band of hæmorrhage or fibrous tissue laid down in the path made by the foreign body. In the later stages when the vitreous had become clear from any blood which had been effused into it, wounds of the retina and choroid were frequently seen, sometimes with the foreign body lying on the retina.

In a few cases interesting observations were made of the defects of the field caused by the various injuries of the retina or optic disc, indicating the arrangement of the fibres in the optic nerve and their distribution in the retina ; while in others the scars in the retina and fibrous bands in the vitreous indicated the track of foreign bodies which had rebounded once or even twice from the retina within the vitreous chamber.

Treatment.—In the treatment of penetrating wounds of the eye there were two aims ; there was a wound of the coats of the eye, usually complicated by the inclusion of uvea, to be trimmed and treated, and an intraocular foreign body to be removed if possible. As mentioned previously these wounds were often large and ragged, sometimes with gaping edges.

When the sclera was involved it was found important first to clear the site of operation fully by enlarging the conjunctival wound and retracting its edges ; and then quite deliberately to free the scleral wound of uvea ; the conjunctiva was then sutured over it, not only to cover but also to brace its edges. In the larger gaping wounds of the sclera the edges were sometimes co-apted by deep sutures not including the conjunctiva. It was possible to remove all traces of prolapse or even

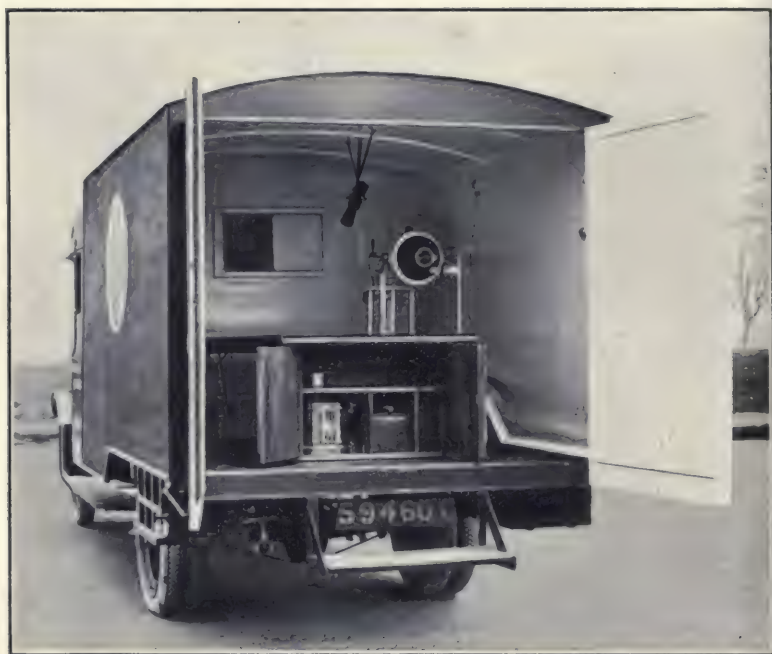


Fig. 3.—Mobile Magnet.

entanglement of uvea many days after the accident, especially when the wound was corneal, but in such cases if the edges did not fall together well they were covered with conjunctiva. The removal of foreign bodies from within the eye was undertaken before trimming the wound of entry, and it was often found advisable to withdraw the particle through a separate incision in order to prevent entanglement of the foreign body in or further laceration of the uvea.

Experience taught that at least half of the intra-ocular foreign bodies were non-magnetic, so that to make a scleral

incision and to insert the small magnet, before it was determined whether or not a foreign body, localized in the eye by X-rays, was magnetic, was strongly contraindicated, as such a procedure would have necessitated an incision of the sclera in at least half the cases to no purpose. Except in cases in which there was a large wound of the sclera, the method recommended was to apply the giant magnet to the cornea to learn if the fragment were magnetic or not, and if magnetic to draw it into the anterior chamber and then withdraw it from the eye with the small magnet through a corneal incision. If a large wound already existed in the sclera, the fragment could often be removed directly through this wound.

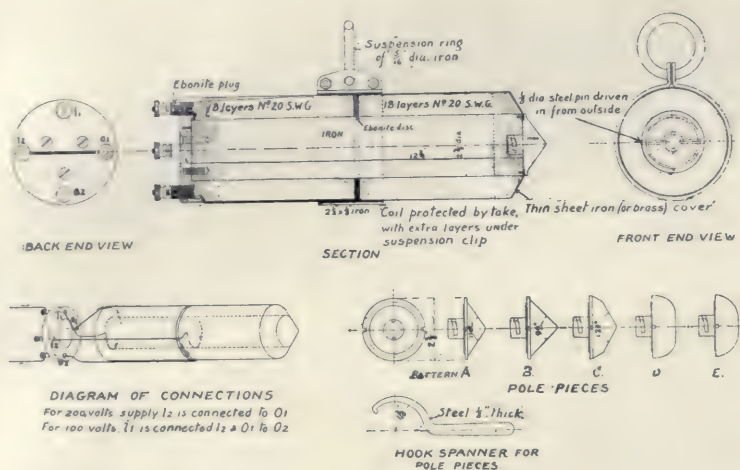


Fig. 4.—Portable eye magnet.

In the early days of the war there were two Haab magnets in France, one at Boulogne and the other at Rouen; later on, a Mellinger magnet was installed at Etaples. Cases of eye injury were constantly occurring which called for the use of a giant magnet in those who had such severe injury to other parts of the body (e.g., a severe abdominal wound or fractured femur) as to make it impossible to transport them at once to the base where the magnet was installed.

To meet the treatment of such cases a mobile magnet was designed (Fig. 3). The vehicle which contained it had the appearance of an ordinary motor ambulance car, but the body was arranged as an operating theatre, containing a table on which the patient on his stretcher could be placed. A Haab

magnet was fitted by the side of the table on a stand which allowed such free movement that it could be placed in any desired position over the patient's head; a ceiling lamp directed a good beam of light on the patient's face; and cupboards for instruments, accumulator, dressings, gowns, etc. were provided. Beneath the driver's seat was a dynamo which could be run by the motor engine when in neutral, and which thus supplied the correct current to the magnet. The mobile magnet was thus quite self-supporting and could be used independently of any particular electric current installed at the hospital to which it was brought.



Fig. 5.—Portable Eye Magnet.

Later on a large portable eye magnet, on the lines of the American portable eye magnet, was designed by Professor Smith of the Imperial College of Science at the request of the War Office and issued to each army ophthalmic centre (Figs. 4-8). This beautiful instrument was calculated to give the maximum of pull for the minimum of weight, and had been so wound that, by a simple variation in the connections of the terminals, it could be worked with currents of either 100 or 200 volts, and could thus be used at any casualty clearing station or base hospital from the X-ray plant. The close of the war soon after its issue prevented any extensive experience of its use.

Results.—As in civilian life, accidents which caused simple perforation of the cornea and corneo-sclera with prolapse of the iris gave uniformly good results. Such cases were not common, the majority of perforating wounds being complicated by the retention of an intra-ocular foreign body.

If the foreign body had merely entered the anterior chamber it was removed without deterioration of vision in practically all cases.

Of the final results of magnet extraction of the other intra-ocular foreign bodies it is difficult to speak definitely, as the injured men are not easily traced. The immediate



Fig. 6.—Portable Eye Magnet in box, with foot switch.

results were not so good as those following similar accidents occurring in civil life ; but this could scarcely be expected. The particles which perforated the eye were often larger and nearly always more irregular in shape than those seen in industrial life ; they were frequently septic, and the interval between the receipt of the injury and the application of the magnet was necessarily greater ; all these facts lessened the chance of preserving good vision.

That there were some remarkably good results there can be no doubt ; a few cases in which either perfect vision or at least very useful sight had been retained have been traced

many months after the operation, and there are many more in which further operation, such as the discission of an opaque capsule or an iridotomy, will improve vision.

In the majority of cases an eye with damaged sight was saved, and this in itself was sufficiently remarkable. In any event, the magnet equipment gave the injured man the best chance of having the sight saved and enabled ophthalmic surgeons to do everything that was possible.

Sympathetic Ophthalmia.—This dreaded disease was most fortunately practically unknown in comparison with its terrible incidence in the Franco-German War of 1870-71, in connection with which it is stated that in the German Army 55·6 per cent. of the ocular injuries were followed by sympathetic ophthalmia.



Fig. 7.—Portable Eye Magnet, showing alternative method of connecting terminals when using 100 or 200 volts.

In France, out of the thousands of cases of intra-ocular injuries only one definite case of its occurrence is known, and though doubtless there have been several which developed the disease later on, it is generally admitted that the numbers are very small.

This happy immunity is probably due mainly to three factors :

- (1) The antiseptic precautions taken in all ophthalmic operations.
- (2) The care with which prolapse or entanglement of uvea in cases of penetrating injuries was excised.
- (3) The prompt and thorough removal of useless dangerous eyes, including those which had been shattered by rupture.

Functional Ocular Disorders.

Night Blindness.—By far the commonest group of functional ocular conditions was that of men complaining of inability to see in the dark.

Ability to see in low illumination varies very greatly in different normal individuals. In cases of retinal degeneration, whether primary or secondary, in xerosis of the conjunctiva



Fig. 8.—Shows method of using portable magnet.

and in the rare familial group, night blindness is a most hampering symptom. In practically all those thus affected, inability to see comes on as soon as the sun sets, and the sufferer has to be led about. Xerosis of the conjunctiva was practically unknown in the army; familial nyctalopia recognized as such was seldom, if ever, met with, but degeneration of the retina, both primary and secondary, was comparatively common.

In by far the larger number of those complaining of this symptom no disease or abnormality could be found. Their night blindness was only partial; it did not come on at sundown, but the individuals affected found that in the dusk or on dark nights they could not see so well as their fellows and many suffered very severely. The condition should probably be looked upon as one of neurasthenia which picked out those who had originally poor acuity in low illumination. It is well known that fatigue has a very marked effect on those whose acuity in low illumination is poor. The illumination which is sufficient when the individual is fresh to enable him to move about in comfort is inadequate when he is tired. It would be expected that the stress of life at the front with its risks and fatigue would greatly accentuate a latent disability.

Large numbers of these men were tested by the ordinary means, the fields were taken, the sight tested with grey types or with Young's test, but no definite defect was found. Probably if some more delicate test for light sense had been used for experimenting with these cases, such as Professor Spearman's, it would have been found that their light sense was definitely lowered.

As would be expected those complaining of the symptom were found amongst all grades of neurasthenia, and also in a small section of definite malingerers in whom treatment was unsatisfactory. In order to maintain the strength of the army, lenience was unwise for the complaint was extremely "infectious," but when a man was obviously worn out a rest was ordered or a change of occupation advised. In doubtful cases the commanding officer of the patient was approached, as far as possible without the patient's knowledge, to find out whether or not the disability was rendering him a nuisance in his unit; if it were, a transfer was recommended.

Functional amblyopia associated with shell shock was a special type of case, which came under treatment by neurologists.

Functional blepharospasm and functional convergent strabismus, of which a considerable number of cases was seen, presented no signs different from those met with in civil practice.

Artifacts.—The two chief characteristics of artificial inflammation of the eye were that the injection was always limited to the lower ocular or palpebral conjunctiva, the upper ocular conjunctiva being as a rule white and the upper lid and cul de sac showing no abnormal signs; and that the signs conformed

to no known disease. A localized conjunctivitis limited to the lower half of the eye was the commonest condition met with, presumably due to rubbing with the finger or to the introduction of some irritant, such as cigarette ash, into the lower cul de sac.

Abrasions, cuts or ulcers of the lower ocular conjunctiva were also fairly common, but perhaps the most characteristic lesion was a symmetrical ulcer of adjacent portions of the ocular and palpebral conjunctiva, such as could be produced by introducing the glowing end of a match between the lid and the eye. In one case a perforating corneal ulcer with prolapse of iris was almost certainly due to some artificial interference, but the mode of procedure was never elicited.

Affection due to Diseases.

Certain other groups of cases, disproportionately large compared with those of civilian practice, were dendritic ulcer and spring catarrh.

The dendritic ulcers were of the ordinary type and ran the usual course, and, as is commonly the case, occurred with outbreaks of *herpes febrilis* on lips and face. Their high proportion was probably associated with the large numbers of various febrile disturbances, such as influenza, trench fever and pyrexia of uncertain origin.

At Boulogne an unusual number of cases of spring catarrh occurred, all of the bulbar type, no instance of the palpebral type being seen. In some cases the efflorescence at the outer and inner margins of the cornea was singularly prominent; they ran the usual course, getting well in the cold weather and improving considerably, even in the summer months, with boric acid, zinc sulphate and adrenalin drops.

Trachoma.—The management of the vast numbers of cases of trachoma, which were present amongst Chinese and Egyptian labour companies in France, was concerned more with prevention than treatment, and details of this eye affection are consequently omitted here. They will be found in "Hygiene of the War" in the chapter dealing with the prevention of trachoma.

Injuries due to Gas Warfare.

The various gases used in warfare which have affected the eyes, may be classified under three headings:—

- (1) Pulmonary irritants.
- (2) Lachrymatory gas.
- (3) Mustard gas.

Pulmonary irritants, of which chlorine and phosgene are the chief members, while so serious in their effects on the lung tissues, caused little ocular trouble beyond a slight and transient conjunctivitis.

Lachrymatory gas, while purporting directly to affect the eyes, and undoubtedly causing great discomfort at the moment, led to no permanent damage. This gas caused intense burning pain in and about the eyes immediately on exposure, associated with profuse lachrymation and inability to keep the eyes open. The conjunctiva was injected and slightly swollen, but no corneal complications either of the nature of grey infiltration or ulceration were seen. There was no lasting blepharospasm, and the neurasthenic element so marked in mustard gas irritation was entirely wanting. The effects passed off rapidly, usually in a few hours, though in some cases some conjunctivitis lasted for a week or so.

In some experiments made by ophthalmic surgeons on themselves with lachrymatory gas (xylyl bromide), exposure to the vapour for five minutes caused severe smarting and lachrymation, but the cornea showed no staining with fluorescein, and the symptoms passed off in about half an hour.

Mustard gas (Di-chlor-ethyl-sulphide).—In addition to its serious effect on the respiratory passages, this was the only gas used in the war which gave rise to any lasting or serious ocular trouble.

Though a very large number of gassed eyes was seen, it is difficult to give definite statistics of the proportion of the men exposed to the gas who had their eyes inflamed in consequence. Many of the mild cases got well quickly and were never seen by an ophthalmic surgeon, while those who were sent to the ophthalmic department of a base were for the most part severely affected.

It was generally agreed amongst those who had had wide experience of these cases that the majority of men who went sick from exposure to mustard gas had some degree of conjunctivitis with or without signs of exposure in other parts of the body, and that the ocular cases could be classified into three groups—mild, intermediate and severe. The milder cases formed at least 75 per cent. The intermediate group, in which there was considerable conjunctival inflammation but no apparent damage to the cornea, formed about 15 per cent.; while the cases with severe inflammation and definite corneal changes formed about 10 per cent.

In summarizing the effects of mustard gas, the time which

elapsed before the man affected was able to return to duty must first be considered, and secondly the damage done to the eyes.

Cases in the first and second groups got perfectly well. The mild cases were as a rule fit for duty in from one to four weeks—on the average in about two weeks—the intermediate group in from four to six weeks.

The severe cases with corneal complications often showed a faint nebulization of the cornea in the line of exposure for some weeks, but this was probably only temporary in the majority of cases. In certain very rare instances the corneæ were completely vascularized as the result of ulceration with the formation of false pterygia. Out of about one-third of all the gassed cases amongst the British, only ten cases were seen with infiltrated ulcer in which the vision was permanently impaired by opacities of the cornea. In only four cases was panophthalmitis seen where the eye was lost.

Taking the severe cases as a whole, but excluding those with deep infiltrated ulcer or panophthalmitis, the men were not fit for duty as regards the eyes in under two to four months.

It may be noted that it was during the summer, when there was greater diffusion of the gas, that the worst cases of affection both of the skin and eyes were met with.

The irritant being in the form of a gas, the clinical picture was entirely different from that caused by burns from solid or liquid caustics. It is of interest and importance to compare these three clinical pictures.

When, for instance, a solid caustic, such as lime or hot metal, gets into the eye, it rapidly lodges between the lid and the globe and there causes the chief destruction of tissue. The main lesion is thus irregular and localized to the spot where the caustic rests.

When a liquid caustic, such as vitriol, enters the eye, it flows over the surface, producing a more generalized lesion. It enters the lower and occasionally the upper cul-de-sac, causing extensive necrosis and, later, ulceration of the ocular and palpebral conjunctiva and also of the cornea.

A caustic first produces necrosis of the superficial layers of the conjunctiva, with coagulative exudate in the underlying tissue. When its action is prolonged, deep necrosis supervenes, which is followed by ulceration as the sloughs separate, and by cicatrization. Ulceration of the cornea may be caused by the direct action of the caustic, whether physical

or chemical, and also secondarily by the cutting off of the blood supply in the surrounding conjunctiva.

The ulceration of the opposed surfaces of the lids and the globe following damage by solid and liquid caustics leads frequently to symblepharon.

In mustard gas irritation the clinical picture was quite distinctive; the lesion though varying in degree was curiously similar in distribution in every case. The caustic was not perceptible at the time of exposure and, as it was in a gaseous form, the part of the eye which received the brunt of the irritant was that exposed between the lids when the eyes were normally open, that is to say, the triangular areas of conjunctiva between the margin of the cornea and the external and internal canthi, and a horizontal band across the cornea on a level just below its centre. It was in this area alone that the severe changes took place. The irritation of the gas in the severe cases was sufficient to cause solid œdema in the deep conjunctival tissue, but unlike burns due to solid or liquid caustics neither necrosis nor ulceration of the conjunctiva occurred. Also that part of the ocular conjunctiva covered by the lids, together with the palpebral conjunctiva, was never severely affected. There was, therefore, no danger of symblepharon so common after burns from solid or liquid caustics.

Occasionally the actual liquid from a mustard gas shell passed into the eye. The lesion then was similar to that produced by burns from other liquid caustics, and necrosis with ulceration of opposed surfaces and symblepharon occurred.

Symptoms.—The symptoms in all cases came on comparatively slowly, on an average about six to ten hours after exposure to the gas. The degree of the burn varied greatly according to the length of exposure.

In the slight cases there were severe stinging in the eye and lachrymation, the lids could not be raised, the ocular conjunctiva was injected, especially in the palpebral aperture, but the cornea was not visibly affected.

In the intermediate group the symptoms were much more severe. The pain was acute, there was blepharospasm and the eyes poured with tears. There was much greater reaction, the skin of the lids was puffy, the conjunctiva in the interpalpebral aperture was swollen and red, and might project between the lids, but in this group also the cornea was not visibly affected.

In the severe form the symptoms were very serious. There was intense burning pain in and about the eyes, associated



A



B



- A. Severe burn in the acute stage.
- B. Severe burn complicated with hypopyon ulcer.

with marked blepharospasm, which for days entirely prevented the man from opening his eyes, and he often feared he had lost his sight. Tears streamed from between the closed oedematous lids, the skin of which might even be blistered.

The conjunctiva in the inter-palpebral aperture, though only slightly swollen, had an opaque yellowish-white colour due to coagulative exudate in its substance (Plate V (a)). This exudate pressed on and obstructed the capillary circulation, thus preventing much chemosis in this area, a condition corresponding with the solid white patch seen in a lime burn.

Meanwhile the ocular conjunctiva, under the upper and lower lids, which in reality was much less affected, was greatly swollen, so that two chemotic folds might be seen protruding between the lids (Plate V (b)).

To the inexperienced or those who made a hasty examination of the eye, the white appearance of the conjunctiva in the palpebral aperture led to the impression that this part was normal, while the chemotic conjunctiva above and below attracted the chief attention and was thought to be more severely affected. In fact this wrong interpretation of the condition led some to the erroneous impression that the poison was secreted by the mucous membrane, and that the part of the eye which was covered by the lids had suffered most.

The fluid, which poured from the eyes in the early stages of these severe cases and throughout in uncomplicated cases, was clear and consisted chiefly of tears; but the conjunctiva, like the mucous membrane of the respiratory tract, was very liable to acquire secondary infection, in which case there was a definite mucopurulent discharge.

The cornea in the exposed area was in the early stage grey and hazy over a band-shaped area stretching horizontally just below the centre, uniting as it were the two triangular white areas of the conjunctiva infiltrated by the solid oedema; above the band the corneal surface usually remained bright (Plate VII (a)).

The surface of the cornea in the region of the grey band was dull, stippled and roughened, that is to say it had the typical "orange skin" appearance when viewed with a bright light and magnifying glass (Plate VII (b)). The grey roughened appearance was due in the first instance to oedema of the epithelium, and later to actual exfoliation of cells. The sensation of the cornea to tactile stimuli was often lowered, and remained so for some weeks.

The cornea being the vulnerable spot, it was only in so far as this was affected that there was any danger to the sight. The condition of the cornea therefore called for the most careful and regular examination throughout, and for this it might be necessary to use a lid retractor where there was much swelling or blepharospasm.

Ulceration in gassed eyes might result from exfoliation of the damaged epithelium, from an abrasion or, in the cases with severe chest complication, from exposure. Exfoliation and abrasion were especially liable to progress to definite ulceration in the presence of secondary infective conjunctivitis with mucopurulent discharge. An ulcer under these conditions readily became infected and infiltrated, leading to permanent opacities with impairment of vision (Plate V (b)).

It was thus in severe cases that impairment of sight might result from diffuse nebulæ of a temporary nature, which might occur without definite ulceration (Plate VII (b)); or from opacities due to ulceration; or from ulceration which, on becoming secondarily infected, might cause onyx, hypopyon, perforation or panophthalmitis.

Where chest complications were severe and the man's general health was greatly lowered, reparative processes were more sluggish, and when the man was lying for a week or two semi-conscious with his eyes half open, the cornea ran a double risk both from the initial effect of the irritant and also from exposure. Ulceration, especially in the lower part of the cornea, was then apt to occur.

In a few cases an infiltrated ulcer of the cornea which might have been due to a direct splash of the liquid appeared early. Such a view was supported where only one eye was thus affected, and the same side of the face blistered and more swollen than the other. In the majority of instances, however, infiltrated ulceration came on late and was associated with mucopurulent discharge; it was then probably due to exfoliation or abrasion of the corneal epithelium associated with secondary infection.

Course.—In the mild cases resolution was rapid. The swelling and injection of the conjunctiva soon subsided, and if the patient's mental and physical tone was not lowered, and he had appropriate treatment, he was usually fit for duty in about a fortnight.

It may here be noted that exposure to gas often lit up chronic inflammatory conditions of the lids. Thus ciliary blepharitis, which for months had been quiescent, might recur and remain



A



B



A. Stage of resolution in mustard gas injury to the eye, showing absorption of coagulative exudate. Cornea has recovered its lustre.

in an intractable form, while styes and chalazia were common occurrences in the stage of convalescence.

In the more severe cases, and especially when the cornea was affected, the period of convalescence was prolonged to several weeks and even months, depending in great measure upon the treatment adopted. The chemotic folds above and below the cornea subsided in a few days, and the ocular conjunctiva covered by the lids gradually paled and became white. The solid œdema in the palpebral aperture, however, often took a week or ten days to absorb. Vascularization gradually spread from the upper and lower sides of the triangular patch (Plate VI (a)), till the whole white area disappeared and the conjunctiva in the inter-palpebral aperture became red. The early clinical picture was thus reversed; the parts which were white became red, and those which were red became white (Plate VI (b)). Thus the appearance of the last stage of the serious cases was almost identical with the early stage of the mild burns.

It was often noted that the colour of the eye, where the solid œdema previously existed, had a peculiar mauve tint similar to that seen in certain cases of episcleritis, and was probably due to the same cause, namely, injection of the superficial vessels of the sclerotic, seen through the episcleral tissue and conjunctiva.

The two symptoms which were liable to persist were lachrymation and photophobia.

In many of the gas cases a neurasthenic condition was very apt to supervene. The sufferer from mustard gas poisoning had often been frightened by exposure to the gas, he had gone through the period when he was unable to open his eyes, which had made him apprehensive that he might be blind for life, and he had often been poisoned and thus had his whole nutrition impaired by inhalation of the gas. Under these conditions local reflexes were liable to persist; to these he was apt to pay too much attention and easily became depressed and neurasthenic. If his mental environment and the mode of treatment were not of a sufficiently firm and tonic nature, he was very apt not only to have his convalescence materially and unnecessarily prolonged, but with certain temperaments to pass on to definite malingering, when the irritability of the eyes was wilfully kept up by rubbing or otherwise irritating them.

Treatment.—An important principle in the early treatment was to reassure the man, at the earliest possible date, that

his sight was not lost. He came down from the line with his lids swollen and stuck together and for perhaps a day or two he had not seen any light. By gently separating the lids and insisting on his recognizing that he could see, great peace of mind was restored, which was an important factor towards mental convalescence.

In the earlier stages when burning pain in the eyes was the prominent symptom, the natural instinct to use cocaine had to be checked, as this only gave temporary relief and tended to loosen the corneal epithelium, the very condition which had to be avoided.

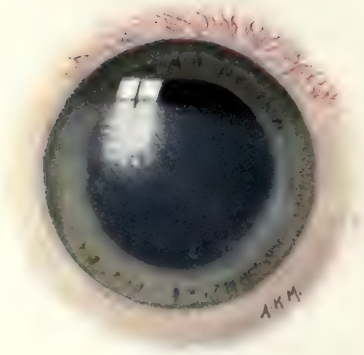
In mild cases, frequent gentle bathing was given with some bland lukewarm lotion, such as boric acid, normal saline or 2 per cent. solution of sodium carbonate. The latter was supposed to have a specific action, though practice showed it had no special value for the eyes, while the mild astringent and antiseptic qualities of boric acid were of definite benefit. Liquid paraffin, a totally unirritating emollient, was dropped into the eyes three times a day.

In severe cases, when there was marked blepharospasm and continued pain, there was no question that atropin ointment 1 per cent. inserted between the lids at the earliest possible date was the right treatment. Much of the pain and spasm was set up by reflex action from irritation, not only of the cornea but also of the iris and ciliary body, a condition evidenced by the contracted pupils. The first application of atropin often gave almost immediate relief.

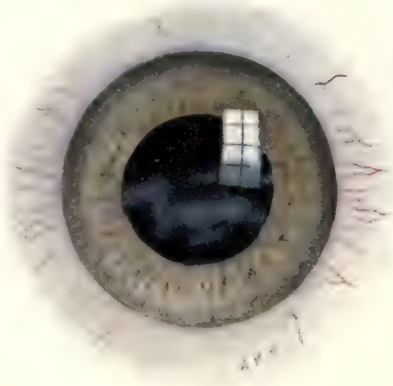
When the cornea was affected, regular use of atropin in addition to frequent bathing was very important, repeated sufficiently often to keep the pupil well dilated, and continued till the cornea had become quite smooth. A shade, or dark glasses, was ordered so long as the pupils were dilated with atropin.

If there was any catarrhal or mucopurulent discharge a mild antiseptic was instilled. The lids were as a rule too swollen and too tender to allow of their being everted and the conjunctiva painted, and it was found that a weak solution of argyrol or protargol instilled twice a day was very efficient in cleaning the conjunctival sac. This was an important procedure whenever the cornea was grey and roughened, for organisms are very apt to penetrate the epithelial layer in which vitality is lowered and to produce an infiltrated ulcer. If this occurred hypopyon might supervene and even actual panophthalmitis followed by loss of the eye.

A



B



- A. Enlarged view of cornea in acute stage of mustard gas burn.
- B. Nebulization of cornea after severe mustard gas burn.

When ulceration occurred, the same measures were adopted, but stricter care had to be exercised to keep the conjunctival sac clean by gentle and frequent bathing, combined with very hot applications over the closed lids four times a day, and to make certain that the antiseptic drops were successfully instilled.

In no cases, even the most severe, where the above line of treatment had been adopted from the beginning, was severe infective ulceration seen. The bad results occurred when the cornea was not properly examined, the grey haze overlooked, no shade allowed, the purulent secretion unheeded, no atropin used, and a stereotyped perfunctory washing with sodium bicarbonate lotion, a supposed panacea, persevered with till the mischief which led to permanent defect had been wrought.

If the ulcer became infiltrated it was cauterized by light application of pure carbolic acid put on with a nearly dry brush slightly moistened by the liquid; it had to be borne in mind that the nutrition of the cornea was already lowered, and a too free application of another caustic might cause extensive necrosis and perforation.

If hypopyon supervened and did not clear up with hot bathing, atropin and cleaning of the conjunctival sac, Sæmisch section was indicated and in a few instances saved the eye.

As soon as the cornea was smooth, or in the milder cases as soon as the primary irritation and swelling of the conjunctiva had subsided, atropin was dispensed with and astringent drops instilled three times a day, *e.g.*,

Boric acid	10 grains.
Zinc sulphate	1 to 2 grains.
Adrenalin (1 in 1,000 solution) ..	$\frac{1}{2}$ to 1 drachm.
Water to the ounce.	

When the pupil had regained its normal size, the shade and dark glasses were removed irrespective of the wishes of the patient. Such protection in the later stages of convalescence only accentuated and prolonged the neurasthenic symptoms. Definite stimulating treatment, both mental and physical, was adopted to restore the normal balance. It was found essential that the man should leave his bed as soon as his general condition allowed, and that he should be ordered a tonic, urged to walk in the open air, and given some occupation to keep his mind off the condition of his eyes.

When photophobia and lachrymation persisted, blisters to the temples every other day, and cold douching (*e.g.* repeated

splashing of the face into a basin of cold water twice a day) were of service.

It cannot be too strongly urged that in the convalescent stage the neurasthenic tendency had to be combated by vigorous mental environment, fresh air, tonics and suitable occupation.

In evacuating gas cases from base hospitals to convalescent depots or to the United Kingdom, it would have been well to group them at definite centres where they would have been under ophthalmic supervision. Had this been done it would

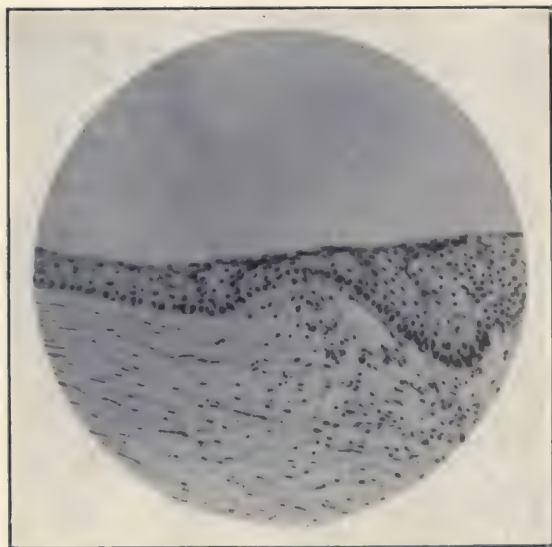


Fig. 9.—Normal corneal epithelium.

have prevented large numbers of cases with slightly irritable conjunctivæ being sent to localities where no ophthalmic surgeon was available, and remaining for months away from duty when they could, under stimulating treatment, have been fit for work in as many weeks.

Pathology of Gassed Eyes.—The pathological examination of eyes which had been gassed showed changes in the corneal epithelium, substantia propria, and in the conjunctiva.

Unfortunately, no material was obtained for the examination of the corneæ of those patients who died in the first few days after being severely gassed, and there is, therefore, no record

of the condition of the earliest stages. The eyes examined were from those who died a fortnight or more after exposure to the gas.

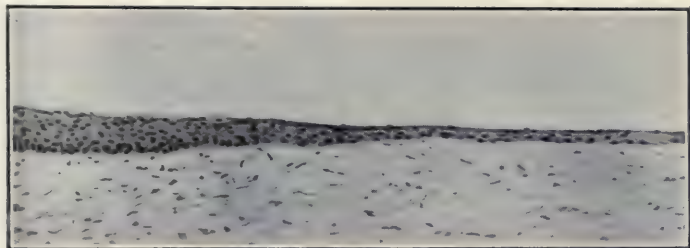


Fig. 10.—Epithelium in a gassed eye, showing the diminished thickness of the corneal epithelium and the replacement of the columnar cells by flattened epithelium.

Sections of these corneæ showed definite changes in the epithelial layer, namely, the thickness of the whole layer was diminished in passing from the periphery towards the centre of the cornea, and the deeper cells, instead of being columnar, were flattened (Figs. 9 and 10). In places there was complete denudation of epithelial cells and Bowman's membrane was exposed (Fig. 11).

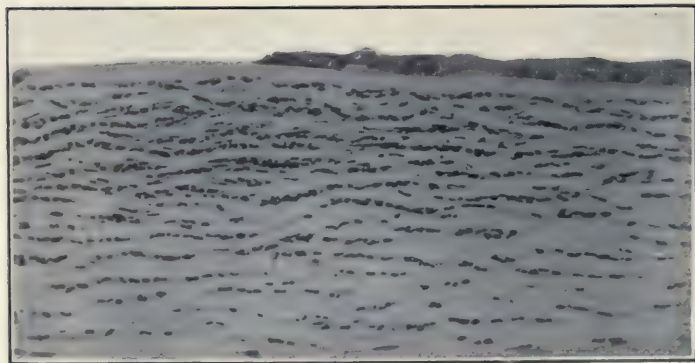


Fig. 11.—Denudation of Bowman's membrane, with cellular infiltration of the substantia propria.

The substantia propria in some cases showed infiltration of round cells between the layers, as is found in other cases of deep inflammation and necrosis (Fig. 11).

In the conjunctiva over the sclerotic in the inter-palpebral aperture granular masses were seen in the sub-epithelial tissue in some sections which probably correspond with the solid white exudate which was seen clinically (Fig. 12).

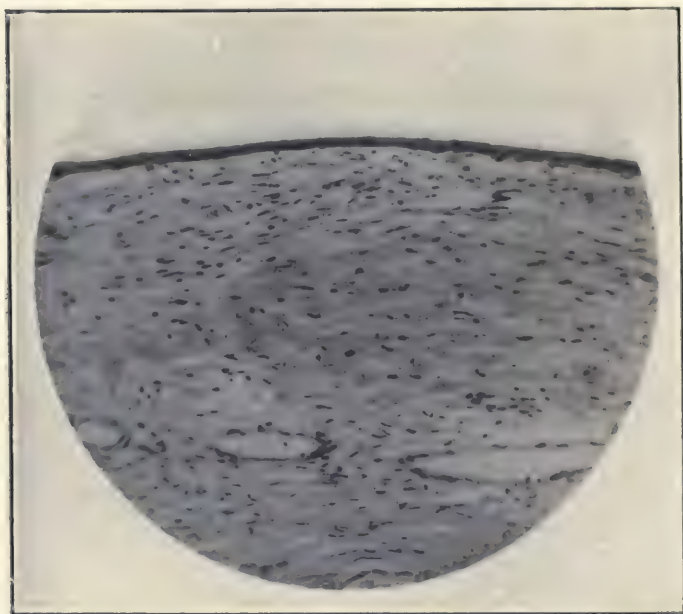


Fig. 12.—Granular masses in the sub-epithelial layer of the conjunctiva at the site of the coagulative exudation.

OPHTHALMIC WORK IN EGYPT.

The campaigns in Gallipoli, Sinai and Palestine presented problems other than those which arose on the Western front. Instead of a long front with comparatively short lines of communication with the base, both Gallipoli and Palestine offered cramped or limited fronts with long lines of communication. In the Gallipoli campaign the front was separated from the base, Egypt, by about 700 miles of sea, no other communications being available; and in Palestine the only line of communication was the railway across Sinai, single for a great part of its length, the distance from Egypt to the Gaza or Jerusalem front being about 150 miles. With a view to the speedy treatment of gunshot wounds of the eye and to the

prevention of trivial cases being sent to the base, it was necessary to have a well-equipped ophthalmic centre as near as possible to the actual front. In the Gallipoli campaign this centre was located at Mudros, on the island of Lemnos, at No. 3 Australian General Hospital, which was equipped with a Haab's magnet and a good X-ray installation.

In the Palestine campaign an ophthalmic specialist was kept as near as possible to the advanced railhead, and just before the final advance to Damascus and Aleppo the ophthalmic centres were situated at Ludd, Jerusalem, Deir-el-Belah, Kantara, Port Said, Ismailia, Cairo and Alexandria. At railhead urgent ophthalmic injuries and all trivial cases were dealt with. All other cases which required rest in hospital and treatment, or which had to come before a medical board for the purpose of classification, were sent to Egypt.

As the military problems of the campaign in the Mediterranean differed from those on the Western front, so also did the ophthalmic affections. Fighting was never so continuous or intense in Palestine as in France, and as trench warfare was not so highly developed eye injuries were not so common.

Statistics of about 33,000 eye cases among British troops are available from the base hospitals and casualty clearing stations in Egypt and Palestine, and though they are by no means exhaustive they give a fair picture of the conditions which obtained.

These cases may be analysed as follows:—

Errors of refraction.. ..	15,530
Conjunctivitis	3,940
No appreciable disease (N.A.D.) ..	2,472
Corneal ulcers	1,298
Gunshot wounds	564
Trachoma	342
Night blindness	131
Shell shock	13
Other eye diseases	8,064

It will be seen at once that errors of refraction or trivial defects comprise nearly 55 per cent. of the total, but as errors of refraction and the problems associated therewith did not present any features peculiar to the campaigns in Gallipoli and Egypt no further mention of them need be made. Similarly, gunshot wounds of all kinds, of the globe, lids and orbit, were comparatively few in number, and do not add to the experience of those who had to deal with similar cases in France, where they were so much more extensive.

Conjunctivitis or ophthalmia was, however, a disease of high importance, and in the case of Turkish prisoners caused grave anxiety. Ophthalmia has always been one of the plagues of Egypt, and in Napoleon's Egyptian campaign caused a disastrous epidemic. This epidemic has always attracted great attention among oculists, probably owing to the fact that a vivid and accurate account of it was published by Baron Larrey, and also by reason of the widespread epidemic of trachoma which developed in all European armies in the years following the Napoleonic campaigns.

Trachoma is endemic and almost universal in Egypt. At least 80 per cent. of the population are trachomatous and 20 per cent. are acutely infectious. Non-trachomatous ophthalmia is also widespread but varies within seasonal limits. About 50 per cent. of all cases of non-trachomatous ophthalmia are gonococcal, 23 per cent. are due to the Koch-Weeks bacillus, and 12 per cent. to the Morax Axenfeld bacillus. Gonococcal ophthalmia is not prevalent in the winter months, but its activity increases in May and reaches its maximum in September, its curve of incidence being identical with the mean temperature curve. Koch-Weeks and Morax Axenfeld ophthalmias do not appear to show any relation to the temperature or season.

In view of these facts and of the generally accepted view that the ophthalmia which so ravaged Napoleon's army was trachoma, great anxiety was felt lest the British army should become infected, and stringent precautions were taken to segregate cases of trachoma. Fortunately these fears proved groundless, for during three years only 342 cases were reported. Only 68 were recent, and of these, as also of the chronic trachoma, a high proportion was found among the Australian soldiers, trachoma being not infrequent in Australia. On consideration of these figures, and of the fact that for three years the British army lived in a country where trachoma is almost universal, that it had been working side by side with the Egyptian Labour Corps, almost all infected with trachoma, that native servants had been employed in messes and as personal servants, and that hospitals had been largely staffed by native orderlies, the army's freedom from trachoma is a remarkable tribute to the high standard of cleanliness and sanitation maintained.

Non-trachomatous conjunctivitis in the British army was never severe, and there was never anything approaching a general or even local epidemic. During the period under review

only five eyes were lost from perforation, staphyloma or panophthalmitis. Gonorrhœal ophthalmia was very rare, only eight cases being reported. The ophthalmia generally was of the simple catarrhal type, the most serious cases, resembling the acute mucopurulent conjunctivitis due to the Koch-Weeks bacillus, clearing up rapidly under treatment. All the usual remedies were used with about equal success; but the experience of both Egyptian oculists and of the R.A.M.C. specialists was that zinc sulphate, except for the very acute cases, was by far the most efficacious antiseptic for the conditions prevailing in Egypt.

Though, as has been seen, the British army suffered but little either from trachoma or from severe ophthalmia, the case was, unfortunately, far different with the Turkish prisoners. Before the war ophthalmia was, next to malaria, the most prevalent disease in Palestine. Turkish and Syrian doctors, who were attached to the Turkish army, stated that ophthalmia did not occur until the troops reached the neighbourhood of Jerusalem and Gaza, where the climatic conditions and the habits and customs of the natives more nearly approach those of Egypt than do those in the more mountainous country further north. There were numerous outbreaks of purulent ophthalmia among the Turkish troops in these districts, and they were severe in character.

The Turkish oculists also found that gonococci occurred in a large percentage of cases, though the ophthalmia was not quite of the clinical type seen in association with urethral discharge in England and other European countries. The swelling of the lids was not so pronounced, though the tendency to perforation of the cornea was quite as marked.

Among the Turkish prisoners in Egypt there was no serious outbreak of ophthalmia until August 1918, when an epidemic of purulent ophthalmia started at Kantara. This increased with great rapidity and was exaggerated by the influx of about 87,000 prisoners, many suffering from acute ophthalmia, taken during the advance from the neighbourhood of Jerusalem to Damascus and Aleppo. In 1918 the number of prisoners with ophthalmia admitted monthly to hospital at Kantara rose from one or two in the early months of the year to 400 in September, 1000 in October and 2000 in November. By December the epidemic had begun to abate, only 200 cases being admitted.

At the prisoners of war hospital, Heliopolis, the epidemic

followed much the same course, the average numbers under daily treatment rising from about 100 in July to 400 in August, 500 in September, 1000 in October and 1200 in November. By December 1918 the average number had dropped to 500, and by the end of the year the cases were comparatively few.

The prisoners on arrival were underfed, exhausted, and in a pitiable condition, dying from pellagra, enteritis, dysentery, broncho-pneumonia, influenza and tubercle, and they had very little resistance to the ophthalmia. The type of ophthalmia in the early stages was that of the acute Koch-Weeks conjunctivitis, there being little of the brawny swelling of the lids, so characteristic of gonorrhœal ophthalmia; but as in Egypt and in the Turkish army, bacteriological examination showed a high percentage of cases in which gonococci were found. The characteristics of the epidemic were the rapidity with which the cornea was affected and the high proportion of corneal ulcers, perforation and panophthalmitis. At the prisoners of war hospital, Heliopolis, where most of the serious cases eventually arrived, the number of eyes removed monthly in 1918 was as follows:—January, 1; February, 3; March, 2; April, 0; May, 1; June, 30; July, 39; August, 34; September, 17; October, 39; November, 218; December, 29.

It was impossible to arrive at the exact number of prisoners affected as, owing to the progressive transfer of batches of prisoners down the line, the same cases were undoubtedly counted twice or three times over in any statistical figures that were obtainable, so that representative figures are only given from two important hospitals for prisoners of war.

There appears little doubt that in Egypt and Lower Palestine the gonococcus can live in the conjunctiva and be transmitted from eye to eye over and over again, without the co-existence of venereal disease, and that in these altered conditions it loses some of its characteristics and is not identical in its action with the gonococcus directly transmitted from the urethra. There were two small outbreaks of typical gonorrhœal ophthalmia in two prisoners of war camps in Egypt, early in December, but these were directly traced to prisoners with urethral discharge, and with segregation and treatment of the venereal disease the epidemics were rapidly got under.

As to treatment, there is little to record. Experiments were tried with all the well-known antiseptics, but there was no evidence that any one was more efficacious than another. The whole value of any treatment of purulent ophthalmia

depends more upon efficient and frequent irrigation than upon the actual nature of the antiseptic. Bandages were entirely forbidden, as there was a tendency among many Turkish, Syrian and Egyptian doctors to tie their cases up, with or without fomentations, with disastrous results. Silver nitrate, especially in the early stages or in patients with little recuperative power, seemed to destroy the conjunctiva and lead to further infection and sloughing of tissues, and was only used in selected cases and not allowed as a routine treatment ; cauterization with pure carbolic acid for corneal ulcers was equally useless in many cases.

In camps where outbreaks of ophthalmia occurred, regular prophylactic daily treatment of every prisoner, whether suffering from conjunctivitis or not, with zinc sulphate and boracic acid drops was carried out with great success, and the epidemics had almost entirely died down by the end of 1918.

As evidence of the bad state of nutrition of the Turkish prisoners, it may be mentioned that in the ophthalmic compound of one prisoners of war camp there were at one time 172 cases of xerosis of the conjunctiva with night blindness, associated with pellagra and all forms of intestinal malnutrition. These cases were put on a more generous anti-pellagra diet and the xerosis rapidly cleared up.

That the ophthalmia was almost entirely due to the personal habits of the prisoners is evidenced by the fact that there was no epidemic of ophthalmia at all in contiguous camps among German or Austrian prisoners, or among interned civilians, though unfortunately a German orderly lost the sight of one eye from gonorrhœal ophthalmia contracted during the performance of his duty among Turkish prisoners.

It is interesting to note that Larrey's description of the ophthalmia in the French army in 1799-1801 accurately represents the symptoms prevailing during the epidemic among Turkish prisoners in 1918, and he expressly states that the tarsal cartilages were not affected. Without entering into the old controversy as to whether or not the epidemic of military trachoma in Europe in the early part of the nineteenth century was due to infection by Napoleon's troops, it appears quite safe to say that, from all the evidence available, the epidemic which so seriously affected Napoleon's troops in Egypt was the same as that which occurred among Turkish prisoners in 1918, and was due to the gonococcus primarily, with some lesser infection from the Koch-Weeks bacillus.

Corneal ulcers were common, especially among troops camped on the desert. They were probably caused in the first instance by abrasion of the cornea with particles of sand, the abraded surface becoming infected by some of the conjunctival organisms. The ordinary corneal ulcers reacted quite well to treatment, and were very seldom complicated by hypopyon.

There was, however, an unusually large number of dendritic ulcers of the cornea, associated with corneal anæsthesia. These were very intractable and prone to relapse, lasting sometimes for months and reacting to no treatment. All the ordinary remedies, such as the usual antiseptic ointments, pure carbolic acid, tincture of iodine or absolute alcohol, were tried, but in the majority of cases the progress was extremely slow. The corneal epithelium grew over a shallow superficial mass of partially necrotic tissue forming a very weak scar, and even when the ulcer did heal it often broke down almost immediately if the patient was discharged to duty.

Generally it was found that the cornea did not heal satisfactorily in the sandy atmosphere of Egypt, and men were invalided home in the hope that the sea voyage and treatment in England might result in a more rapid cure.

The causation of these dendritic ulcers was obscure. By some observers it was held that they were associated in some way with malaria ; by others it was supposed that they were due to the large doses of quinine given to cure the malaria. No evidence produced ever seemed sufficient to justify these statements. Sir J. W. Barrett, the well-known oculist of Melbourne, stated that dendritic ulcers were, in his own experience, common in those parts of Australia where the occurrence of sand, wind and heat produced a climate resembling that of Egypt. He also stated that malaria did not occur in Australia.

In the early months of the war in Egypt many soldiers, both English and Indian, complained of night blindness. Careful examination was always made, but very little actual disease was found. A few cases of genuine retinitis pigmentosa were seen, but no cases of conjunctival xerosis among the British troops, and in the great majority of cases no ocular disease existed, and the men appeared to be in good condition and well fed. Careful observation led to the conclusion that the night blindness was either grossly exaggerated or a fiction. The men alleged to be so afflicted managed never to injure

themselves in the dark, and after they were told they would not be invalidated for the condition nothing more was heard of it.

Among the Turkish prisoners night blindness was much more common and was undoubtedly caused by malnutrition. As mentioned above, there were at one time in the prisoners of war camp at Heliopolis 172 cases of pronounced xerosis of the conjunctiva with night blindness, associated with pellagra and other forms of intestinal disease. These cases all cleared up with rest and a generous diet.

One fact should be put on record in connection with this campaign. Malaria, malignant and benign, was very prevalent in both the British and Turkish armies in Palestine. Large doses of quinine were given, both in intensive methods of treatment and spread over long periods. Inquiries were made everywhere, but there was no record of a single case of quinine amblyopia.

In the campaign in Egypt and Palestine from 1915-1918, the standards of sanitation and cleanliness maintained were responsible for the remarkable freedom from contagious diseases of the eye ; but ophthalmia is still a source of real danger in an army with less stringent precautions, the severe epidemic among the Turkish prisoners in 1918 being a very forcible reminder of this fact.

OPHTHALMIC WORK IN MACEDONIA.

When the ophthalmic work was organized in Macedonia ophthalmic centres were established, and placed so that there was one for the base at Salonika, one for the lines of communication, and one each for the Struma and Doiran-Vardar fronts. Three ophthalmic surgeons were attached to the base centre. One of them visited other hospitals at the base when eye patients were unable to come to the centre, and occasionally he was required for various forms of ophthalmic work at a distance. There was one ophthalmic surgeon at each of the other centres. The base centre placed in a general hospital was provided with a clerk, also a practical optician and a stock of lenses, thus allowing men with errors of refraction to be fitted with spectacles and supplied with glasses on the same day as they were examined. The Doiran-Vardar centre also had an optician and a stock of lenses. Cases of injury and disease of the eye were evacuated from the corps area centres to the base centre as soon as possible. Beds were available for eye cases in the hospitals where the ophthalmic centres were placed.

The following notes on ophthalmic work in Macedonia are derived solely from a few observations made by Major Usher, during the period from August 1916 to May 1918, when he was serving first, for a few months, as "ophthalmic specialist" and afterwards as officer in charge of the base ophthalmic centre.

The chief interest of the ophthalmic work in Macedonia is confined to a few points in connection with malaria.

Retinal Hæmorrhages in Cases of Malaria.—To form some estimate of the frequency of retinal hæmorrhage in malaria, a series of consecutive cases in which the malarial parasite was reported present in the blood was examined during the winter months from 16th November 1916, to 28th March 1917. In each case both eyes were examined, one pupil having previously been dilated by means of homatropine. In 503 men 1,006 eyes were examined. Retinal hæmorrhage were found in six eyes of four men. Of 211 cases of subtertian malaria, three had retinal hæmorrhages, five eyes being affected. Of 292 benign cases and "those of uncertain origin" only one had a retinal hæmorrhage, one eye being affected. There was no opportunity for examining a similar series at the season when malarial fever was most prevalent, namely, from June to October.

The form and situation of the hæmorrhages, as found in 18 eyes of 13 men with malaria, including the four cases already mentioned, were as follows:—

Subhyaloid hæmorrhages were present at the macula in ten eyes of eight men; the hæmorrhages were single in every eye but one. Other forms of hæmorrhage were usually small and flame-shaped. All hæmorrhages occurred at the macula or close to the optic disc.

With regard to the cause of the hæmorrhages, a blood count made in five of the 13 men with retinal hæmorrhage showed that three were anæmic, the number of red blood cells per c.mm. in one case being as low as 1,950,000, and in another 1,060,000. In four more of the 13 men there was clinical anæmia, three others had had recurring attacks of malaria, and the remaining case died from "malaria and nephritis." There is reason to believe that in a large proportion of cases the hæmorrhage is a result of anæmia secondary to malaria. In eight of the cases the parasite reported present in the blood was malignant tertian, in four cases benign tertian, and in one it was not recorded. Dudgeon and Clarke examined the iris and retina microscopically in several fatal cases of pernicious

malaria and found definite obstruction of capillaries ; in other instances no true obstruction was present, but the red cells infected with parasites showed the common tendency to drift to the wall of the vessel.

Keratitis in cases of Malaria.—By far the most common ocular manifestation seen by the ophthalmic specialist in cases of malaria was inflammation of the cornea. In summer time, especially during June, July and August, these cases were much more frequent than in the winter months. A large majority of them showed evidence of dendritic ulceration, and incomplete, though often pronounced, anæsthesia of the cornea was a marked feature. Herpes, more especially on the lips, was a frequent concomitant. The conjunctiva was usually reddened, and the palpebral portion had commonly a velvet-like aspect. The clinical forms of corneal lesion included vesicular eruptions consisting of small vesicles distributed irregularly in a group, or arranged in a row, and more rarely a single vesicle was present. In the dendritic types of ulceration usually a single ulcer was present ; sometimes there were more, as many as five having been seen at the same time on one cornea. Their size and shape showed wide variations, some being quite small, others extending nearly across the cornea. A curious form consisted of several dendritic ulcers radiating from a single point. Sometimes small ulcers alternating with vesicles were arranged in a row, or parallel rows, each forming a continuous line. Rarely there was a large superficial roughly circular ulcer with dendritic processes. More common were small circular and frequently multiple ulcers. There were still other forms of ulcer with unusual shapes. Extensive and sometimes minutely pitted opacity of the cornea was not infrequent either at the periphery or as a large circular central area. Although these opacities were at once obvious, it was only on close inspection and staining with fluorescein that sometimes a vesicle or small ulcer was found which accounted for marked symptoms of irritation.

Dendritic keratitis was obstinate in healing, most men remaining on an average between four and five weeks at the base centre. The average duration of the keratitis, however, was longer than this, for a number of cases had already received treatment in other hospitals before they were transferred to the centre. Recurrences were frequent. Iritis was not troublesome, and although hypopyon formed once or twice it soon cleared up. The onset of keratitis was usually soon

after a malarial attack, and histories given by the men indicated that the onset commonly occurred any time from some hours to seven days after the malarial attack. In some cases the cornea became affected only after several attacks of malaria. The treatment consisted in the local use of atropin, and when photophobia was troublesome shades or dark glasses were worn. It is doubtful if any benefit was derived from various remedies that had been applied to the cornea. General treatment for malaria was adopted.

Quinine amblyopia does not appear to have affected many men in view of the large quantities of quinine that were administered in many cases of malaria. Chavernac, the ophthalmic specialist of the French Army, mentions only three cases. H. Edgar Smith and Major Usher between them saw 22 cases of quinine amblyopia in the British troops and one in a Bulgar prisoner of war. A large quantity of quinine had been administered immediately before the onset of blindness in each of them. One case had been given 50 grains intravenously and 170 grains intramuscularly, 220 grains in all, during a period of 43 hours. In two cases the dose was taken accidentally by the mouth, "two large mouthfuls of quinine solution" in one, and "four to six tablespoonfuls of quinine solution" in the other. The majority of the cases were not seen for at least a week after the onset of blindness, when contracted fields of vision, pallor of the optic discs, and narrowing of the retinal arteries were observed. Two cases, however, seen within twelve hours of the onset of blindness, require particular mention. The first, seen in December 1917, was a man, age 24, with malignant tertian malaria, who had received within 17 hours 60 grains of quinine intravenously and 20 grains intramuscularly. When examined ten hours after the onset of blindness his pupils contracted feebly to light, and vision was reduced to distinguishing fingers with each eye; some hours earlier there had been no perception of light. The optic discs had a normal colour and the retinal arteries were not appreciably contracted. Two months later the optic discs were much too pale and the retinal arteries definitely narrowed. R.V. = $\frac{2}{3}$; L.V. = $\frac{2}{3}$; fields of vision were much contracted.

The second case, that of a patient seen in February 1918, had received at least 50 grains of quinine. When examined after four and a half hours he complained of defective vision, his pupils were dilated and did not contract to light, and there was no perception of light in either eye. The optic discs

had a good colour, the retinal vessels were of normal size, and nothing abnormal was detected in the fundus of either eye. He had blackwater fever and died.

A third case, a Bulgar, aged 23, with benign tertian malaria, received 180 grains of quinine during the three days preceding his loss of vision, which was reduced to counting fingers. When examined 24 hours after the loss of vision, his optic discs were normal and his retinal vessels of full size. The fields of vision appeared to be full when tested by hand movements, and he stated that his vision was again quite good. A case such as this, in which defect of vision lasts for a short time, may later on show pallor of the optic discs and narrowing of the retinal arteries as occurred in one of the cases.

The presence of a cilio-retinal vessel in the eye of a man with quinine amblyopia deserves notice. When he was seen eight days after the onset of blindness there was no perception of light in either eye, marked pallor of the optic discs, and thread-like arteries. The cilio-retinal vessel, situated at the outer edge of the left optic disc, was apparently narrowed. The view that quinine causes amblyopia by primarily contracting the retinal arteries is not supported by this case, unless it is assumed that there is also a primary contraction of the cilio-retinal vessels; otherwise complete abolition of vision in the left eye would not have been expected, nor would the cilio-retinal vessel have been contracted.

Of other ocular diseases night-blindness may be mentioned, as considerable time was spent in the examination of this complaint. These important and often troublesome cases were much more prevalent from May to October than during the other six months. Trachoma was not common, and only exceptionally was seen among the British.

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CHAPTER XVI.

INJURIES TO THE EAR.

MORE men were incapacitated through loss of hearing in the war of 1914-1918 than in any other war in history. Not only are the actual numbers higher, but the proportion of injuries to the ear is much higher in comparison with other injuries than has hitherto been recorded. This is accounted for by the magnitude of the conflict, the numerical strength of the armies in the field, the prolonged series of engagements and great artillery combats, and especially by the use of much more powerful explosives than any previously employed in battle.

Direct wounds of the ear were frequently fatal owing to the injuries to the brain and great vessels in the vicinity. Severe wounds of the cranium, whether fatal or not, were often accompanied by indirect injury to the ear. Many cases of deafness were attributable to the dynamic concussion of high explosives in mines, shells and bombs, and affected all classes of combatants.

Capacity for military duty was also interfered with by ordinary diseases of the ears, due in many cases to causes inseparable from the strenuous conditions of the campaign. Trench warfare in a half-waterlogged country with exposure to cold and wet accounted for numbers of cases of "common colds" and nasal catarrh, which sometimes led to inflammation, or else lighted up previously existing inflammation in the middle-ear. In at least one region overseas outbreaks of measles, followed by a steady stream of cases of severe otitis media, were reported. Nor were troops at home free from epidemics which predisposed to middle-ear diseases. Wherever there were cases of severe common colds, influenza, tonsillitis, bronchitis, or pneumonia, there was always a certain percentage of otitic diseases; and in hot climates "camp dust" was believed to be an important factor in causing the nose, throat and ear diseases which prevailed.

Furunculosis and inflammation of the external ear also proved to be familiar and troublesome complaints.

It is important to notice that certain disturbances in the ear caused disabilities in connection with flying, and that vertigo is a phenomenon no less important than deafness, and nearly always traceable to some definite derangement in the ear.*

* These disturbances are dealt with in the chapters on the medical aspects of aviation in Volume II of the Diseases of the War.

That the organ of hearing may be damaged by explosions was known in the earlier days, though the nature of the injury appears to have been left to the imagination. Over 300 years ago Hildanus records the case of a soldier deafened by a pistol shot. Apparently the man was asleep in camp when his companions in merriment fired a pistol close to his ear. From the description it seems evident that this caused giddiness, vomiting, great pain and deafness, and that the soldier did not regain his hearing until after the lapse of a long time.

In the course of his aural practice in the military hospital in Vienna during the wars in 1864 and 1866, Gruber found deafness due to rupture of the drum from gunpowder explosions in only one case. This was caused by a hand grenade in the battle of Königgratz.

Between 1867 and 1877 Chimani saw, among 5,041 aural patients, only two cases of ruptured tympanic membrane due to the detonation of a gun.

During the Franco-German War of 1870-1871 Friedländer met with only twelve cases of indirect injury to the ear in the German army.

In the army of Japan during the Russo-Japanese conflict in 1905 only 101 cases of deafness are reported.

It cannot be supposed that these figures include all the ear injuries observed in former wars. It is well known that so long as only one ear is affected many men do not complain. In comparison with other injuries sustained at the same time, a defect in one ear may seem trivial and is often unrecorded.

Examination of Recruits.

Among those men who applied to serve with the army during the first years of the war numbers were rejected owing to obvious deafness or suppurating diseases of the ears. Yet, generally speaking, no routine aural examination was made at that time, nor any systematic inspection of the drums of the ear of every applicant for the British army. This was not considered necessary, especially in the case of the infantry. Capacity for military service did not necessitate perfect hearing, nor indeed complete freedom from aural disease, but if such defect or disease was very obvious it was sufficient ground for rejection. If the applicant answered questions immediately when spoken to in an ordinary tone of voice, and did not appear at all deaf, nothing else was required so far as the ear was concerned. Without routine inspection of the drum of the ear it was inevitable that a considerable proportion of

men with ear disorders present at the time of enlistment were admitted, and afterwards it often proved to be a matter for regret that no record of the aural condition was kept for future reference at the termination of service in settling claims for pensions or awards.

No doubt the decision as to the condition of the ear rested with individual recruiting medical officers, for several instances are recorded of men otherwise eligible who were rejected again and again because they bore the scar of a simple mastoid operation, though soundly healed and with no impairment of hearing, whereas some with polypi and active disease in the ear had no difficulty in passing the recruiting medical officer, especially when the need for "man-power" was paramount.

It is recorded that "a very large number" of soldiers enlisted with discharge from the ear which they had had for many years. As civilians they were accustomed to the discharge and neglected the ear unless in pain or discomfort, and it was often only when more exacting conditions prevailed that the attention of regimental medical officers was called to the state of the ear.

A statement describing the appearance of the ear drums at the time of enlistment or mobilization, and available for reference on demobilization or on discharge from the army, in the case of claimants for pensions on account of aural disabilities, would no doubt have been an undeniable advantage to the State, and would have materially assisted the medical officers under the Ministry of Pensions to distinguish cases of ear disorders which originated before the war from those caused by injuries due to the war.

The routine inspection of the drum membrane was included in the examination of applicants for commissions, especially in the flying service, from 1917 onwards.

For the Canadian Contingent there were regulations for classing men in the service in different categories as regards hearing power.

These regulations were as follows:—

"Hearing and Nasal Conditions.

Category 'A.'—A soldier who can hear 15 ft. or better in each ear by ordinary voice, and who has no organic disease of the ear.

A soldier who has hearing of 21 ft. in either ear, but with little or no hearing in the other ear, but without active organic disease.

No soldier with a discharge from his ears shall be placed in Category 'A.'

Category 'B.'—A soldier who has hearing of 15 ft. in either ear and little or no hearing in the other ear, and has no active disease in either ear.

A soldier who has better hearing than 12 ft. in each ear, but has a discharge from either ear of a moderate degree, or is subject to frequent recurrent discharge from the ears, of a moderate degree.

Category 'C.'—Soldiers who show symptoms of chronic ear conditions, such as hearing reduced to less than 15 ft., with freely discharging ear or ears, or shell concussion deafness.

A soldier who has fully and recently recovered from a mastoid operation would be placed in Category "C" for three months and then regraded.

Category 'D.'—Cases that show repeated signs of recurring serious ear conditions, such as recurring mastoid pain, free formation of granulation tissue, indications of bone disease, or free, full and offensive discharge from the ears, should be examined by an otologist with a view to being placed in Category 'D' for discharge as permanently unfit."

Establishment of Ear Centres.

During the first few months of hostilities cases of incapacitating deafness or ear disease were widely scattered and formed only a small percentage of the battle casualties which were transferred from the front to the base hospitals in France. Whenever recovery of hearing seemed doubtful or likely to be protracted, the cases of decided deafness and of ear disease were evacuated to the United Kingdom with other casualties, and distributed to various military hospitals for treatment or convalescence. Eventually the steady accumulation of ear cases in centres in the United Kingdom attracted attention and the Director-General of the Army Medical Service decided to establish aural departments and appoint aural surgeons to certain military hospitals. Or, according to expediency, arrangements were made for aural cases to be referred to the special departments of neighbouring civil hospitals. It should be mentioned that among the foremost hospitals for aural cases on a considerable scale was that provided by the Government of the Dominion of Canada and established at Folkestone in 1915 for injuries and diseases of the eye and ear. All the staff were specialists in the eye or ear, and at that time the commanding officer was a well-known eye and ear specialist from Ottawa.

Various observers record that a large number of civilians joined the army suffering from diseases of the nose and throat which predispose to middle ear affections, such as adenoids, enlarged tonsils, nasal obstruction and chronic diseases of the nasal sinuses. There are sound reasons for checking and treating these cases at the outset, for sooner or later deafness, noticeable discharge from the ear, onset of pain, some mastoid complication or fever of unrecognized origin caused these soldiers to be brought to the notice of their medical officers. At some periods comparatively few of such cases were sent to hospital, but sometimes the base hospitals received them in batches, apparently as a result of periodic inspections by the individual regimental medical officers. Although forming

a relatively small percentage of hospital admissions, they accumulated, and wherever there were large concentration camps a definite number of ear cases was always found with protracted, chronic or recurrent complaints.

The administrative authorities consequently saw the necessity of establishing ear centres on a more comprehensive scale, and these were accordingly set up as special departments in certain general or stationary hospitals.

With the growth of the British army in France it was found advisable to concentrate ear cases, whether battle casualties or not, in special departments which were attached to one or other of the established hospitals in France. In September 1916 there were in Boulogne four hospitals, including a Canadian General Hospital, which had set aside beds for these cases. No. 3 Canadian General Hospital had been equipped by the Government of Canada in 1914 for dealing with this department of surgery, its commandant, Colonel H. S. Birkett, being a well-known aural surgeon. Comparatively few hospitals at the outset were so equipped for dealing with aural cases, either as regards *matériel* or personnel. It is interesting to note, however, that as regards personnel, at a time when no special appointments were made, a number of aural surgeons and laryngologists joined the forces in quite different capacities, some as administrators, others as regimental medical officers, some as combatants, at least one, Captain W. A. Porter, who was killed, being employed as an artillery officer; others served as general surgeons; others in advisory capacities, and a number undertook researches both officially and unofficially. It is significant that in whatever capacity they served, their clinical colleagues recognized the value of their special experience when questions of difficulty arose in connection with injuries or diseases of the ear, nose or throat. As to *matériel*, difficulties were encountered not merely at the outset, though endeavour was made to overcome them in the course of time. These difficulties were naturally greater in the more distant campaigns. In Egypt, for instance, where it was not anticipated that there would be any need for aural surgery, no aural surgeon had been appointed to the army in June 1915, but, owing to the number of ear cases, an aural clinic was organized at one of the general hospitals in conjunction with the ophthalmic clinic, for which provision had been made. Both clinics were under the care of the same staff, with the use of 100 beds for ear, nose and throat cases. These provided heavier work than the ophthalmic cases, and

though the department was only improvised, 1,474 patients were dealt with during the first six months, including 530 cases of middle ear suppuration, and 610 of deafness from other causes; 182 operations were performed. Sir James W. Barrett was eventually appointed consulting aural surgeon in Egypt in 1916, and aurists were attached to the principal hospitals and also, as in France, to certain stationary hospitals. Aural surgeons were sent to India and other distant stations. They were also placed in casualty clearing stations and in some of the field ambulances.

The need for aural surgeons nearer front line troops in France was noted in August 1917, when the D.M.S., First Army, drew attention to the "desirability of obtaining expert opinions in cases of deafness complained of by infantry soldiers, who were being marked as unfit by regimental officers without expert opinion," for it was quite impossible for a regimental medical officer to discriminate in every case between true and simulated deafness.

It was arranged that such cases should be examined at No. 4 Stationary Hospital, Arques, where, however, "it was possible to deal with only a limited number (*e.g.*, 10) each day." Similar instructions were also drawn up in September 1917, for the distribution of the work of the same nature to the ear, nose and throat specialists in stationary hospitals in the Third Army area.

In the Near East the placing of aurists on lines of communication, though only in the later stages of the campaign, enabled comparatively unimportant cases to be treated and returned to the front without being sent to the base, and also expedited transmission to the base of all cases of an important and urgent character.

It is not possible to ascertain what proportion of hospital accommodation was provided elsewhere for ear cases, or the actual number of aural surgeons employed as such, nor are complete statistics of ear injuries of the war obtainable. It would therefore be idle to attempt an estimate of the actual numbers of ear cases dealt with, but that the numbers would prove to be great is known from figures which were published by the French and by various medical officers in unofficial reports, and from the numbers of pensioners with deafness.

During 18 months from 15th April 1915 to 1st October 1916, Sourdille alone made observations on 700 cases of war deafness, including 327 of concussion from detonation and 373 cases of traumatic otitis media, out of a total of 6,171 ear, nose and throat cases attending the Limoges centre.

At Lyons, Lannois and Chavanne observed 1,000 cases of deafness among soldiers in 18 months, from the commencement of hostilities until February 1916, which included 677 cases of true war deafness and 323 of catarrhal perforative and non-perforative middle-ear diseases. In one British ear centre in France, Mortimer alone saw over 14,000 ear, nose and throat cases during three and a half years of the war. Other aural surgeons also saw very large numbers.

War injuries of the ear were found to be not the only lesions requiring a medical officer's care. Other aural affections, whether old or recent, were numerous, and while some were compatible with combatant military service, provided certain precautions were taken, others called for specialist treatment with a view to complete and speedy cure.

On the Western front the number of ear injuries and diseases was of course far higher than in the other theatres of war.

Injuries involving the Tympanic Membrane and Tympanum.

By far the most frequent injury to the ear during the war was rupture of the tympanic membrane. It proved to be of greater importance in a military sense than at first appeared likely. That a rupture had occurred was not always obvious either at the outset or later when it had healed, or when, on the other hand, complications arose and made the diagnosis in relation to a traumatic origin uncertain; yet upon its timely recognition and correct treatment from the first the future capacity of the soldier for military service frequently depended.

The injury was in some cases due to direct, in others to indirect, causes. Any severe wound of the head, even without fracture of the temporal bone, as well as direct wounds of the ear, may produce rupture of the drum, but the commonest cause was due to "shell bursts." Strictly speaking, this is a "direct" form of violence, though writers often regard it as "indirect," for with the detonation of a shell or bomb the gases evolved produce such a sudden and tremendous increase of atmospheric pressure that the explosion represents a sphere throwing out radii of atmospheric projectiles, any of which may impinge directly on the outer surface of the unprotected drum membrane, which is consequently invaginated, stretched and bruised, or completely penetrated. The actual process of rupture is essentially similar to that observed in deep sea divers, *e.g.*, the sponge divers of the Mediterranean as described centuries ago by Aristotle. At a certain depth the drum membrane yields to the density of the water and is ruptured.

Aviators with inefficient eustachian tubes, diving suddenly from high altitudes into dense atmospheric strata, are liable to injure the drums, and the same injury occurs in caisson divers.

In the case of "shell-bursts," the sudden elevation of atmospheric pressure is more intense when the explosion occurs in an enclosed space, such as a cellar, dug-out, gun-pit or trench. Both drum membranes were then apt to burst. Above ground, in the open, only one drum was likely to be injured, namely, the one which happened to be directed towards the "radii" of the explosion.

Contusion of the Tympanic Membrane.—A drum which resists rupture may be stretched or relaxed, or some vessel may give way causing localized hæmorrhages within its interstices, without laceration of all the laminæ. This condition was also seen in airmen.

Diagnosis of Tympanic Rupture.—Diagnostic and therapeutic measures, admitted to be correct when employed in non-traumatic affections of the ear, must be withheld in cases of suspected recent injury. The correct method of diagnosing ruptured drum is to see it, and to see it soon after the injury has been inflicted. Ordinarily this is achieved by means of the speculum* and illuminating mirror or electric head lighter, after obstructing debris has been removed from the meatus with requisite instruments without resort to the syringe.

Symptoms.—Fluid blood may be seen escaping from the meatus; a recent or dry clot may be visible. Sometimes there is no sign of hæmorrhage from the ear.

If the patient is conscious he may draw attention to deafness at once; in other cases he may not do so until after other injuries have been attended to.

A patient with a recent injury will occasionally volunteer the observation that air whistled out of the injured ear when he blew the nose; he should be told to desist and not repeat the performance in case an uninfected tympanum be infected from the pharynx in this way. The intact tympanum is not so liable to be infected by self-inflation as a tympanum with a ruptured membrane. Should infection of the middle ear take place, the rule prohibiting the use of the syringe and of lavage no longer applies, for irrigation is then the most convenient method of removing the purulent exudate from the meatus and wound.

If not rendered unconscious at the moment of injury the

* Siegle's speculum (Peter's modification), judiciously used, is often very useful.

patient usually notices a sudden explosive noise in the ear with pain; often there are giddiness and ocular nystagmus and the injured man staggers or falls; he may vomit and suffer in some degree from cardio-vascular shock symptoms. There is often tinnitus, which occasionally becomes distressing.

The rupture, which is almost always in the inferior segment, is usually linear or rounded, with inverted or everted margins, but varying in size and in the apparent extent of loss of substance in different cases. Only at the outset is the appearance distinctive, when the irregular blood-stained edges of the tear are seen. After a week or two the unhealed traumatic perforation may be indistinguishable from the perforation due to otitis media.

No doubt many genuine cases of ruptured drum membranes were seen with extensive loss of membrane substance, or when suppuration was present, and were erroneously regarded as cases of long-continued otitis media by aural surgeons who saw the patients for the first time many weeks after the injury had been inflicted. It was then often virtually impossible to differentiate the traumatic from the non-traumatic cases of otitis media. This difficulty was inevitable, and could only be overcome by early examinations of the drum membrane and the preservation of the reports of such examination.

A small tear in the tympanic membrane, if not infected, tends to heal quickly, but if infected there is likely to be prolonged or sometimes permanent disablement. The application of medicated lotions in the form of "ear drops," or the use of the syringe, was found to be followed by suppuration in the majority of cases in which this treatment was applied. The instillation of glycerine, peroxide of hydrogen, etc., mingling with blood, cerumen and with mud and dirt with which the ear was generally bespattered, was universally acknowledged to favour the process of infection, and wherever this "wet" treatment was applied, suppurative otitis media developed within the first week following the injury.

Special instructions were drawn up warning medical officers of the risk attending indiscriminate syringing. These were first issued in 1914, were repeated in 1915, and again and again up to the latest stages of the war. The French also insisted from the first upon the immense importance of avoiding infection of the middle ear. Sourdille, who was with a field ambulance, wrote warning his confrères that "all wounded with bleeding from the ear run the risk of having their ears syringed," and of the probable consequences thereof.

That rupture of the drumhead has taken place is often not evident either from the history or from external appearances. When a blood clot becomes dry in the external auditory meatus it may resemble dark cerumen. A man sent down from the front complaining of deafness was quite likely to be treated by syringing, sometimes at his own request, if a syringe was available. An orderly would be told off to perform the duty when medical officers were pressed with more important cases, for to syringe the ear is regarded as a simple procedure, which an intelligent medical orderly could be entrusted to carry out. Owing to lack of appreciation of the warnings referred to, cases of deafness, erroneously attributed to wax, might be unwittingly converted into cases of otitis media. Whenever the clot was dislodged and the traumatic perforation exposed to infection, germ-laden particles could be washed directly into the tympanic cavity. Suppuration which then followed was often almost characteristically intractable, perhaps owing to the presence of grit and mud particles, which played the part of foreign bodies.

It is to avoid such misfortunes that the aural speculum, headlight and appropriate instruments are essential implements, the usefulness of which became more evident with the progress and increased magnitude of the war; for had they been more generally used overseas cases of deafness need not have been evacuated to England from distant places in order to have deafness cured by removing wax from the ear.

Preventive Measures.—Wool or gauze impregnated with plasticine and moulded into plugs was advocated and used for the prevention of rupture of the tympanic membrane.

Ear protectors, such as the Mallock-Armstrong, which broke the dynamic force of an explosion without occluding the meatus completely, were also employed.

Celluloid plugs were issued, but it was stated they had produced dangerous burns of the ear where they had become ignited.

In gun-pits protection was essential, and as the above devices were often mislaid, some medical officers instructed officers and men to make their own plugs with melted wax from candles worked up with wool, and, according to Captain H. Gordon Greaves, these proved most efficient protectors of the tympanic membrane.

Treatment.—From what has been already written, it is evident that after the injury the immediate treatment advocated at aid posts or field ambulances is forbearance. Only the outer

parts of the ear should be cleansed, but no moisture must enter the meatus ; a dry dressing should be applied and the patient sent to the casualty clearing station, thence if necessary to the nearest aural centre as soon as possible. There the medical officer, with the aid of the forehead light, proceeds to cleanse the meatus by the dry method, and concludes by introducing a strip of cyanide gauze, or by insufflating boric powder according to the extent of the injury. With these precautions it has been found that hospital treatment required was of very short duration, according to Bryant only five to twenty-one days.

Wounds of the Ear and Temporal Bones.

Injuries of the ear and temporal bones vary from the most trivial contusion or abrasion of the pinna to the most formidable disruption of one or both petrous bones.

A modern rifle bullet will penetrate the cranium at distances up to 2,000 yds. Fired from greater ranges the bullet is more likely to be retained in the head. Proximity to a bursting shell and its explosive violence are factors which affect the retention or penetration of shell fragments, shrapnel bullets or other projectiles. The site of entry and direction of travel of the missile at the moment of impact also influence the character of the injury. Every conceivable form of wound appears to have been met with.

The most severe wounds of the ear are often immediately fatal owing to concomitant injury to the brain, great vessels or spinal cord. Their number can never be told. Harvey Cushing observed that after the introduction of the British steel helmet the wounds of the penetrating type with lodgment in the cranium both of projectile and bone splinters were commoner in the region of the ear than in the parietal region. The explanation given is clear, for he remarks that "a projectile with sufficient velocity to penetrate the steel helmet as well as a skull would kill in the unprotected temporal and sub-occipital regions, and that the penetration with small projectiles so commonly seen in these regions would not occur if the parts were protected by the helmet."

On account of the high mortality of auro-petrosal wounds a helmet should be devised which would protect this region also, adjacent as it is to the most vital parts of the central nervous system, namely the medulla and pons.*

* The German helmet provided this form of protection.

It has been estimated that the mortality from injuries to the head, including those of all degrees of severity, in patients who survive long enough to receive surgical treatment, has been reduced to approximately 10 per cent. from what were formerly considerably higher figures. For obvious reasons the percentage is likely to vary with circumstances. If 10 per cent. is accepted as a fair estimate it would mean that out of 1,000 cases of head injury many of the 900 survivors have defects of hearing; and in the 100 that soon succumbed, in spite of obtaining surgical aid, the injury was a wound of the temporal bone in over 27 per cent. Sepsis in some form or other was the cause of death in the majority of these mortally wounded cases. The sepsis was almost always established before the patients reached the base. It was known that wounds of the temporal bone which involved the mastoid cells or tympanic cavity were exceedingly likely to prove fatal if they became septic within the first few days after the injury was received.

Hutton, who adopted Cushing's classification of head injuries, group VII of which includes "wounds of (a) orbito-nasal region, (b) auro-petrosal region, with brain exposed and meninges opened," mentions his experiences at a base hospital which received cases of head injuries 36 to 48 hours after they had been wounded. It happened during a period of temporary dislocation of the casualty clearing stations, but it is here referred to because he found what might be expected, that orbito-nasal cases which survived the journey to the base were much more numerous and were in better general condition than the auro-petrosal cases; the latter usually arrived in a moribund condition, which indicated their gravity and the necessity for early treatment.

Wounds in the mastoid region should be treated on the same surgical principles as wounds of other parts of the cranium, allowing for the greater complexity and special functions of these parts. Early in the war one authority, who foresaw that injuries in the mastoid region were likely to be common, did not advise operating on the mastoid even if sepsis intervened, "unless matters did not mend when treated by syringing and cleansing the wound," but later experience led him to abandon this conservative treatment.

De Martel laid down that the guiding principles of surgical intervention in head wounds were:—

- (1) The removal of mechanical results of fracture, *e.g.*, compression by bone splinters, by blood clot.

- (2) Arrest of hæmorrhage.
- (3) Cleansing the wound by removing loose fragments of bone, destroyed integument and muscles, hair, clothing.
- (4) Establishment of drainage.

If these principles are applied to wounds of the mastoid region, it will be seen that waiting until sepsis is well established cannot be justified, much less waiting until sepsis attains the ascendancy.

From observations made on numerous head wounds, including mastoid wounds, the views held early in the war were considerably modified. Although a certain proportion of cases of mastoid injury recovered without the necessity for operation, the mortality from sepsis was great, and it was found that this could be reduced by earlier surgical intervention.

Those surgeons who at first took the view that operations for injuries of the mastoid should not be performed gathered their experience for the most part from observations on survivors with clean rifle bullet wounds who reached England. If the same surgeons had seen the injured within 24 hours and could have traced these cases afterwards it is more than likely they would have decided that to cleanse a mastoid wound it was necessary to open its cellular system completely and to extirpate every cell.

It is an undeniable advantage for a surgeon who operates on the mastoid in war to be perfectly familiar with the intricacies of the mastoid cells and the varieties of mastoid infection. The necessity for this thorough drainage of wounds of the temporal bone was generally recognized later. As a matter of fact, only a few aural surgeons accustomed to deal with diseases of the temporal bone and their intra-cranial complications were called upon in the first instance to treat wounds which involved the regions with which they were most familiar. It has proved difficult to obtain expressions of opinion based on actual experience from all those who would have been qualified to express them, but it is interesting to be able to say that the waiting attitude which was favoured at first was abandoned, and the claims for early intervention in mastoid wounds, as in other cranial wounds, came to be recognized in the later stages of the war.

As mentioned elsewhere, the frequency of mastoid wounds which call for surgical treatment is not high. Approximately, 5 per cent. of the patients wounded in the head who reach the advanced hospitals alive have auro-petrosal wounds.

As examples of wounds of the temporal bone, four out of 77 cases of penetrating wounds of the cranium which Velter observed in hospital not far from the French front lines, involved the auro-petrosal region; of these four, one survived.

As it is with cases of this kind that the aural surgeon should be prepared to deal, the following notes of these four cases are of value :—

Case 1.—Wounded 22nd June 1915, by shell in right mastoid region. There was a large contused wound, with free hæmorrhage from wound and from the external auditory meatus.

Symptoms.—Headache, vomiting, torpor. Repeated loss of consciousness for short periods. Small rapid pulse. Complete palsy of the right facial and external rectus oculi.

Treatment.—23rd June 1915. Operation. Mastoid and middle ear opened up. Fragments of bone, stones, wood removed. No metallic foreign body found. A fracture seen extending to the petrous. The dura mater and lateral sinus were intact. The wound was packed open with gauze, after applying iodine solution.

24th June.—Slight suppuration of wound observed.

1st July.—X-rays showed no metallic projectile present.

3rd July.—Less torpor; no vomiting; still some headache. Slight suppuration and palsy of 6th and 7th nerves persist. Total deafness on right side and partial deafness on left side. Patient was giddy and unable to stand or walk. Nystagmus was noticed to be "bilateral, irregular, slightly rotatory, increased on horizontal deviation." Optic neuritis was discovered.

25th July.—Wound healed. There was some right hemiparesis and asthenia with palsy of 6th and 7th nerves. Speech was slow and in monotones. The vestibular reaction was not tested. It seems certain that injury of the labyrinth must have occurred.

The patient was evacuated 27th July 1917, and a year afterwards was found to be well except for the deafness.

Case 2.—This patient scarcely had a chance of recovery, because he was wounded and caught up in barbed wire entanglement from the 23rd to the 27th June 1915, when he was conveyed to hospital. He was then semi-conscious, with a bullet wound which entered in the right parotid region and emerged by an irregular wound in the right inferior occipital region level with the external occipital protuberance. There had been free hæmorrhage from the ear.

Operation.—General anæsthesia. Mastoid exposed, and fracture found involving the external auditory canal, mastoid and occipital bones. The dura mater was not opened, but a tear in the lateral sinus was found. The sinus, however, bled freely until a muscle graft was applied.

He died early next morning, either of shock or from the sepsis of the wound.

Case 3.—Penetrating shell wound of right mastoid with laceration of the lateral sinus; free hæmorrhage from the wound and from the ear.

Wounded: 8th July 1915. *Operation:* 9th July. Coma, stertor, vomiting, pyrexia and small rapid pulse preceded a fatal termination on 11th July.

Case 4.—This was a penetrating wound of the left parietal region with radiating fractures, one involving the left temporo-mastoid region. There was hæmorrhage from the left ear and from the nose. The patient was admitted three hours after being wounded, and died a few hours later.

Sir Charles Ballance described a case of gunshot wound of the temporal bone which called for operation some years afterwards. The following are the notes of this case :—

7th June 1917.—Shrapnel wounds, at Messines, right mastoid region and over right upper jaw. Unconscious for some time. Operation at the casualty clearing station, Bailleul, on neck and jaw wounds. Owing to headaches, vertigo or discharge from ear, a mastoid operation was performed on 14th November 1917, but discharge continued, and various methods were employed for arresting it.

March 1920.—Operation. Extensive removal of carious bone; no labyrinthine fistula. Ten days later the cavity was covered by an epithelial graft; rapid healing; and by October 1920 all symptoms disappeared.

Sir Charles Ballance and Sir James Dundas-Grant also described the following similar case, that of a gunshot wound of the temporal bone, necessitating a mastoid operation two and a quarter years later.

Gunshot wound inflicted near Cambrai on 2nd December, 1917. The bullet entered the left temporal region, and the point of exit was behind the apex of the mastoid process. Considerable hæmorrhage occurred. The missile apparently crossed the tympanum on the inner part of the osseous meatus, damaging it and the cartilaginous meatus and the mastoid process. This was followed by profuse foul discharge, for which many plans to effect a cure were carried out.

10th March 1920.—Operation by Sir C. Ballance. Patient was suffering at this time from foul discharge, much pain, vertigo, and mental depression. The mastoid wound was widely opened. Much carious and necrotic bone and infective granulation tissue were removed.

20th March 1920.—Epithelial grafting operation. Rapid healing resulted and all symptoms disappeared.

Injuries of the Auricle.

Hæmatomata, contusions, abrasions, cuts, with laceration and destruction from burns, were found to be of importance, chiefly in relation to wound infection, deformity and stenosis, and interference with hearing. Severe hæmorrhage from wound of the pinna alone was rare, as it readily yields to pressure.

Infection leading to suppurative perichondritis is the cause of slow healing; deformity and atresia of the meatus and deafness often necessitated plastic treatment after the wound healed.

For the most part these minor injuries could be treated like other superficial wounds, by cleansing, sparing excision of uncleanable and destroyed tissue and by primary suture. To avoid infecting the fibro-cartilage, West advised that sutures should not penetrate the perichondrium, and if in spite of this precaution suppurative perichondritis set in, causing necrosis of the fibro-cartilage, healing was much hastened by excising the portion of cartilage involved.

Deformity resulting from partial or total loss of the auricle, for which no well-planned plastic operation appears feasible, can be concealed by some simple textile shield. Artificial flexible auricles became procurable, and were obtained through instrument makers.

Wounds of the External Auditory Meatus.

These wounds were not infrequent. They varied with the velocity and size of the projectile, its direction and the depth of the wound. When severe and deep they were usually fatal from intracranial complications; when confined to the meatus, they were liable to lead to more or less complete occlusion after healing.

The fibro-cartilaginous meatus was often directly involved in severe injuries to the auricle, while the osseous meatus was frequently injured either directly or indirectly in association with extensive fractures of the cranium, injuries of the mastoid portion of the temporal bone, tympanic cavity or temporo-mandibular joint. Not rarely the meatus was traversed by bullets entering the head either in front or behind, and sometimes the meatal walls were splintered by projectiles entering from the side.* In certain rarer circumstances missiles have been impacted in the fundus of the meatus, becoming imbedded in the mastoid or petrous portion of the temporal bone, rarely without fatal consequences. In a case, described by Kisch, in which there were no external signs of injury, a spent bullet penetrated deeply into the external meatus and lodged firmly in the tympanum, where it was discovered and removed by the surgeon during an operation for chronic suppuration of the middle ear many months after the infliction of the injury.

When there was stenosis or atresia the stricture could often be excised and the exposed subcuticular surface lined with skin graft. A meatus has frequently been restored in this way.

Disturbances of the Middle and Internal Ear.

Gunshot wounds and similar direct injuries which involve the osseous meatus, when not rapidly fatal, are practically always accompanied at the moment of injury by severe shock, concussion of the brain, loss of consciousness and other disturbances of function of the central nervous system. In the event of recovery of consciousness, vertigo, nystagmus, vomiting, facial paralysis and deafness are first observed. In a few days the vomiting ceases, the nystagmus becomes less noticeable and the vertigo less intense. Staggering gait is evident when the patient begins to get about, though it is usually overcome after a few weeks' exercise and disappears altogether in a few months' time. Recurrent "attacks of vertigo" seldom

* Specimens of these are in the War Office Collection in the Royal College of Surgeons' Museum.

occur in these cases. More or less facial paralysis remains at least for some months ; though its ultimate recovery cannot be foretold, it need not be despaired of for at least 18 months.

Injuries of the Ear Associated with Facial Injuries.

Any part of the face may be the site of entry or exit of a projectile which directly injures the ear. Typical examples of such wounds are found in patients who recovered, and in specimens of head injuries in the War Office collection in the Museum of the Royal College of Surgeons. The track may pass antero-posteriorly through the orbit of the same or opposite side, above the orbits, below the orbits, and involve the external auditory meatus of the petrous portion of the temporal bone. In oblique wounds the nasal chambers or pharynx were generally implicated, and the risks of meningitis were extremely high. Many cases of ear injuries which escaped vital injury were ultimately to be found under treatment in hospitals for facial injuries, in hospitals or hostels for the blind, and in hospitals provided for jaw and dental injuries.

When these cases were systematically examined unilateral deafness or tinnitus, with or without evidence of a perforated tympanic membrane, was found to be extremely common.

Treatment of Mastoid Wounds.

The conclusions as to the treatment of mastoid wounds may be summed up as follows :—

Wounds of the mastoid require surgical exploration as do other wounds of the cranium.

While technical skill in performing partial craniectomy was soon acquired during the war, the surgery of the ear calls for special knowledge, experience and judgment. Just as it was possible to do too much to the mastoid, so was it possible to do too little.

All serious operations on the ear or its neighbouring parts require special instruments and a knowledge of the particular technical proceedings on the part of the surgeon.

De Martel found the advantage in the elevated position in operations on the head, and this was rendered possible when local anæsthesia, consisting of novocain, adrenalin and scopolamine,* was employed.

He rightly opposed the practice of opening uninjured dura for encephalic hæmatomis "*until the region is aseptic.*"

* Novocain, 1 gramme. Adrenalin, 1 milligramme to 200 c.c. of physiological serum. Scopolamine, $\frac{1}{2}$ milligramme. Up to 100 c.c. may be injected.

Where the dura has been penetrated by projectile or bone splinters pulped semi-liquid brain then flows out. To encourage the flow, gentle stretching of the open dural wound was found safer than incision. Judicious exploration of brain tracks digitally for bone splinters, etc., carried into the brain from the mastoid wound should be undertaken, as in the wounds of the vertex, though with even greater precaution.

The well-known mastoid operations do not need special description, but during the war probably in many cases the radical mastoid operation was done needlessly early without awaiting the effects of a more complete but simple mastoidectomy alone.

On the other hand cases were seen in which an insufficient mastoidectomy had been performed, only a few cortical cells having been opened, with imperfect drainage; consequently suppuration persisted, often with fatal results. As a general rule, if any hearing is to be preserved on the injured side, the removal of drum and ossicles should not be undertaken simply to diminish purulent discharge, but when it is necessary to drain the labyrinth the ossicles and drum must of course be removed.

Vertigo in Head Wounds.

Much experience of vertigo in head wounds was obtained in neurological centres.

In head wounds the patient almost always complains of vertigo as well as headache. Neither the site, the dimension, nor the depth of the wound has any apparent connection with the intensity or type of the headache or vertigo, a fact which may give rise to serious mistakes.

M. Babinski has pointed out that in whatever part of the skull the site of the wound may be, it is possible that there may have been a perturbation of the labyrinth, causing the vertigo of which the patient complains.

This giddiness must be distinguished from true disorders of the labyrinth, which is often by no means easy. In the auditory examination the vestibular function must be tested, and this will sometimes enable the actual cause of the vertigo to be ascertained.

Chatelin observed that out of 1,200 cases with wounds of the skull examined by him, 300 had wounds of the occipital region, among which unilateral or bilateral affections of the labyrinth were especially common, with impairment of hearing and labyrinthine vertigo.

The same author observed that the only important complication, and a very frequent one, of wounds of the temporal region is lesion of the auditory apparatus on the same side as the wound. The examination of this organ must never be neglected.

In discussing wounds of the frontal lobe he states that unilateral deafness may exist on the wounded side, or even on the opposite side, or there may be bilateral diminution of the acuteness of hearing. Extension of the fracture to the petrous bone may be found. Rupture of the tympanum and disorders of the labyrinth caused by concussion are most frequently found. There should always be a most careful examination of these auditory disorders. He gives detailed descriptions of the procedure for examining the auditory and vestibular apparatus.

Injuries of the temporal lobe alone have never been observed to cause deafness. The use of such terms as "cortical deafness" and "word deafness" was based on the supposition that there was an auditory centre in the temporal lobe where the auditory impressions of sounds or of words spoken or written were stored; this has not been verified by any clinical cases or by observation in nerve injuries, according to Pierre Marie. Mott's case of bilateral embolism of the middle cerebrals and deafness is excluded. A frequent complication of wounds of the temporal region is some lesion of the auditory apparatus on the same side as the wound. There may be mere lacerations of the tympanic membrane, or more or less serious lesion of the internal ear. There is, as a rule, in case of fracture from extension, complete peripheral seventh nerve palsy as well as deafness; lesions of the labyrinth may be the cause of vertigo, nausea, or lateropulsion.

Symptoms of labyrinthine as well as of cerebellar wounds diminish regularly. Asynergia, hypermetria and disordered gait diminish under the patient's watchful control.

That essential organ, the labyrinth, is frequently injured in head wounds, especially in the occipital region, and as the similarity of the symptoms makes the differential diagnosis particularly difficult, it will be useful to describe the labyrinthine syndrome as consecutive to wounds of the skull.

Lesion of the labyrinth may occur alone or with a lesion of the cerebellum, and either separately or together they may cause certain kinetic and static disturbances of equilibrium. Lesions of the vestibular labyrinth may be consecutive to a wound of any part of the skull.

By the group of vestibular tests, as employed in otology, it is possible to ascertain the condition of the vestibular labyrinth and whether it is injured even when there are no auditory disturbances. It is also of value to distinguish the disorders which are due to the labyrinth from those which are due to the cerebellum. In fact it is the only important means of differential diagnosis which can be made in cases of head injuries presenting disturbances of co-ordination and of equilibrium.

In this way ophthalmology, neurology and otology combine to sift the problems which beset one or other in cases of head injury.

The technique of labyrinth tests has been carefully described by numerous writers. Briefly they may be enumerated as rotation (acceleration and deceleration), caloric tests by cold air, Dundas-Grant's methods, galvanic tests and compression.

Nerve Deafness.

There was a very common form of deafness, usually absolute for air and bone conduction, which in the absence of any evidence of injury was difficult to explain. It was more frequent in those who suffered some severe shock ; there was often a history of being buried by a shell without any visible signs of injury being discovered. The patients were undoubtedly sick men ; they were not conscious malingerers. The deafness was often associated with other disturbances, such as loss of voice, narrowing of the visual fields, unusual areas of tactile anæsthesia, muscular tremors of the outstretched hands, anomalous paralyses and exaggerated deep reflexes. The auditory "jump" reflex may be obtainable in spite of the deafness.

Such cases often recover with a counter-shock after rest and general treatment, or else by means of hypnotic suggestion with or without the influence of electric and other forms of stimulation.

It was by no means easy to distinguish simulated profound deafness from genuine psychical deafness, but the malingerer was often inclined to be sullen and defiant, and, though he had all his wits about him, repeated hearing tests might reveal some important inconsistency. On the other hand, true psychic deafness is accompanied by signs of anxiety, fatigue and mental strain. The imputation of being a suspected malingerer often increased the patient's depressed state.

Major A. F. Hurst's observations of cases of functional

deafness and deaf-mutism in soldiers in the neurological section at Netley led him to conclude that functional deafness and deaf-mutism were a form of auto-suggestion and therefore akin to hysteria. Whether or not there was any actual momentary deafness resulting from the high explosives, the possibly deafening environment may make such an impression on the mind of the soldier, especially when the hearing has already been impaired by previous disease, that the man may be convinced that he is now permanently deaf, and so by auto-suggestion becomes actually deaf. A ruptured drum alone was of small importance in explaining the profound defect in hearing in these cases, and in no way influenced the rapidity of recovery in hysterical deaf-mutism.

Hurst found it was very much easier to cure hysterical deafness accompanied by mutism than it was to cure pure hysterical deafness without mutism, because by simple persuasion and re-education the mute can be taught to use muscles employed in speech, and sudden excitement is enough to provoke involuntary speech. From the moment a word has been uttered involuntarily, it is easy to convince the mute he is cured. When this occurred in the deaf-mute the return of speech generally convinced him that he could also hear; he therefore listened, and the auditory path to the cerebral cortex was reconnected.

Even deafness without mutism was almost always cured by suggestion under hypnosis, provided the deafness was not so profound that the patient could not even hear shouting through an ear trumpet.

Hurst describes the auditory jump reflex, which some had erroneously regarded as evidence of conscious hearing, as follows:—"A sudden noise normally causes an individual to jump and blink and at the same time his pupils dilate; the jump, at any rate, is a protective reflex, and represents the preparation for flight or fight."

In war neurosis this reflex is exaggerated. The researches of Sherrington and Forbes on the decerebrated cat show that the "jump reflex" is independent of conscious hearing. The presence of a "jump reflex" is merely evidence that some essential portion of the auditory path as far as the mid-brain is intact.

Jones-Phillipson, who examined a considerable number of deafened soldiers in the field, and traced the subsequent history of his patients, came to the conclusion that the majority recovered their hearing, though in some cases only after a long time.

To cure psychic deafness, such means as those adopted by O'Malley when otologist at the Brook Military Hospital, Woolwich, were sometimes useful. He described two cases of functional total deafness with shell-shock, in neither of whom was there any discoverable injury. While stimulating the labyrinth with cold water irrigation, as soon as the patients were becoming profoundly giddy, he shouted down a speaking tube into the ear, and convinced them they were not deaf. They afterwards conversed in the ordinary way.

Scott reports a case of a young pensioner who had been drawing a pension for deafness for 15 months and was cured in as many minutes by methods which had been adopted at the National Hospital for Paralysis and Epilepsy, London.

This man had a fine physique; he had been awarded a medal for bravery in the field; he had been blown up by a shell and afterwards experienced symptoms attributed to shell-shock. After being in hospital some time he became stone deaf in both ears, and had begun to lip read. He said he could hear nothing when tested in the usual way by air and bone conduction. The drums were intact and the vestibular caloric tests caused normal nystagmus. Dundas-Grant and Scott found that the loudness of his voice increased when Barany's noise-machines were applied to the ears. These inconsistencies justified the expectation that he would certainly be cured, even after 18 months of total deafness. Very loud whistles of different pitches close to the ear were now admitted to be faintly audible. Speaking tubes and resonators were then used, and with the aid of a little faradization by Dr. Yealland the patient answered to the voice in a dark room, at first loud, then whispered speech at 20 feet. He admitted being completely cured, saying he wished to rejoin the army.

Pathological Investigations.

In the investigation of the pathology of deafness due to high explosive, bomb and shell bursts, the researches of J. S. Fraser during the war are most important. Various theories have been postulated to explain the loss of hearing in cases of so-called indirect injury.

Some presumed that hæmorrhage must take place in the inner ear spaces, or that the neuro-epithelial sacs of the membranous labyrinth must be injured, but Fraser's work gives little support to these hypotheses.

It seemed feasible to suppose that in "shell-deafness" the lesion might possibly be found in the brain, but many aural surgeons, including Milligan, Westmacott, Shuter and others, were dubious as to the occurrence of any organic brain lesions, and Chatelin stated they had not been observed.

J. S. Fraser and J. Fraser found the following were the demonstrable changes of importance :—

- (1) Rupture of the drumhead (except in one case in which there was a ceruminous plug which protected the drum).

- (2) Free hæmorrhage in the middle-ear spaces.
- (3) Hæmorrhages in the fundus of the internal ear in three of the four cases.
- (4) Minute hæmorrhages seen among the fibres of the facial and vestibular divisions of the auditory nerve and in the canal of the tensor tympani muscle.
- (5) In one case there was a very thin layer of hæmorrhage in the scala tympani, just internal to the membrana secundaria; the ossicles were all intact and there was no rupture of membrana secundaria or of the footplate of the stapes.

J. Gordon Wilson, of Chicago, devoted himself to the study of nerve deafness at the Canadian hospitals in Folkestone and France, and at casualty clearing stations in the Ypres salient and on the Somme. He came to the conclusion that there were two classes of nerve deafness.

- (1) True nerve deafness with profound loss of hearing by bone and air conduction.
- (2) A lesser degree of nerve deafness in those who have the fixed idea that they cannot hear.

Wilson found that only cases in the second group yield to suggestion and recovery.

According to him the cases of nerve deafness met with in war may be distinguished as follows :—

- (1) Cases of nerve deafness in which there has been destruction of the cochlea and of the semicircular canals or their nerves.
- (2) Cases of nerve deafness with visible damage to the conducting mechanism such as ruptured tympanic membrane or hæmorrhage into the middle ear without rupture of the tympanic membrane.
- (3) Cases of nerve deafness without any visible or demonstrable lesion in the conducting mechanism when they come under observation.

Like many others, Wilson's early clinical investigations of nerve deafness, following the effects of high explosive, led him to believe that he was dealing with some ultra-microscopic change in the synapses of the auditory tracts. His later pathological observations, together with those of others, led him to conclude that organic changes in the peripheral organ of hearing or in its nerve offered a more satisfactory explanation of the cause of the deafness and vertigo, "for the progressive recovery of hearing, so constantly observed, suggested in the light of our pathological and experimental knowledge that

we are dealing with injuries of the nature of contusions, with œdema, capillary hæmorrhages and changes in the myelin sheaths and molecular changes in the nerve cells."

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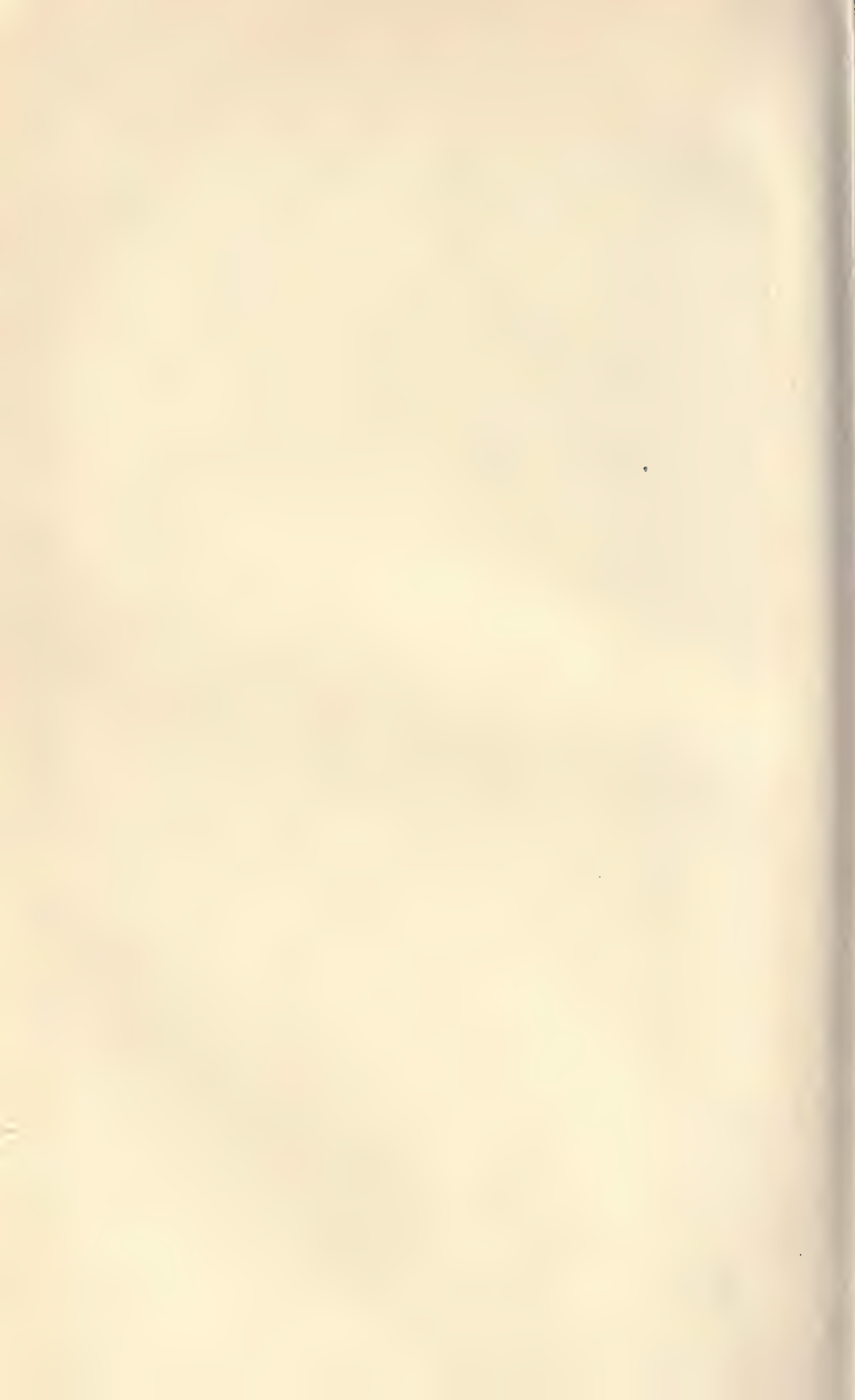
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